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DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

FISCAL YEAR 1978 PROGRAM FOR RESEARCH AND DEVELOPMENT

DARPA

STATEMENT BY
THE DIRECTOR OF THE DEFENSE
ADVANCED RESEARCH PROJECTS AGENCY
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DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

FISCAL YEAR 1978 RESEARCH & DEVELOPMENT PROGRAM.

STATEMENT

BY

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BEFORE THE SUBCOMMITTEE ON RESEARCH & DEVELOPMENT OF

SENATE ARMED SERVICES COMMITTEE.

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TECHNOLOGICAL INITIATIVE AND THE NATIONAL SECURITY ISSUES OF THE 1980'S

I. INTRODUCTION

When I appeared before this committee last year, I outlined an investment strategy which focused on some key questions whose answers are deeply rooted in advanced technology. There is little doubt in my mind that these questions could become the national security issues of the 1980's. Let me review them briefly:

- Are there technologies on the horizon that could make possible a space-related use of high energy lasers and could such a laser system in the hands of the Soviets threaten our vital satellite network and strategic deterrent capability? Conversely, could such a laser serve the United States in some defensive way?
- Are there technologies on the horizon that can provide surveillance capable of detecting aircraft and warning us of missile launches?
- Is a new class of undersea surveillance systems possible that could detect and localize submerged submarines at great range with sufficient accuracy to target them? What are the limits of ocean hearing? Can the oceans really be made "transparent?"

- What is the nature of armor on the battlefield of the future? Are there technologies that could permit unique tradeoffs to the age-old parameters of mobility, agility, armor, and firepower? Could such technologies result in a new and better class of lower-cost armored vehicles?
- What can technology do about the seemingly endless spiral of increasing costs? For example, can we dramatically reduce the cost of jet engines by making them out of new types of ceramics instead of costly and strategically critical metallic superalloys? Can the sophistication and low cost represented by the pocket calculator and digital watch be used to simplify the maintenance problems of our equipment and make it more reliable?
- What are the technological initiatives in the command and control area that could enable us to use our current forces more effectively? For example, can packet switching, intelligent terminals, or computer-based decision aids significantly improve command and control?
- Can we develop a new class of airborne systems with the capability of "assured penetration" of enemy air defense systems?
- Are there technological breakthroughs possible which could lower the cost or greatly increase the speed, range, and endurance of small undersea vehicles?

Even two years ago some of these questions would have seemed like something out of a modern day Jules Verne novel. However, as a result of DARPA initiatives, while difficult technical problems remain, the technologies to answer each of these questions in the affirmative are on the horizon today and require little in the way of major, unknown, conceptual breakthroughs to make visionary answers to these questions a reality. But what are the implications to our security assuming that we or the Soviets are successful?

For a moment, I'd like you to consider:

- Space Defense - Both the United States and Russia depend heavily on space assets. Ponder the consequences of a space associated system that could protect our own satellite resources while possessing the capability to destroy enemy satellites in a surgical and timely manner.
- Anti-Submarine Warfare (ASW) - Ponder the consequences of an ability to not only detect but to localize and track quiet submarines at long range.
- Undersea Vehicles - Ponder the consequences of unmanned undersea vehicles that are difficult to detect which are capable of conducting themselves in a manner similar to airborne remotely piloted vehicles (RPVs).

- Passive Surveillance - Radar is the key to air defense systems but it also discloses the presence of such systems and makes them vulnerable to jamming and anti-radiation missiles. Ponder the consequences of a long-range air defense system which does not reveal its presence to penetrating aircraft.
- "Really Smart" Weapons - Current smart weapons require clear weather and a man in the loop, vulnerable to enemy counteraction, to accomplish their mission. Ponder the consequences of weapons that seek out and destroy specific targets such as tanks and surface-to-air missile (SAM) sites without the need for a designator; weapons that can wait for their specific targets to appear; weapons so accurate that conventional warheads could perform some of the tasks reserved today for nuclear weapons.
- Threat Independent Electronic Warfare - Electronic warfare cannot do its job if the characteristics of the threat are not known ahead of time. Ponder the consequences of electronic warfare suites that are virtually independent of the threat. No more SA-6 surprises. A threat is evaluated and the appropriate response is generated--on the spot--not after the force is attrited.
- Submarine Launched SAMs - Submarines today have very limited ability to defend themselves against the

airborne anti-submarine warfare (ASW) platforms widely used by the Soviets. Ponder the consequences of giving the submariner the ability to actively defend himself, while still submerged, against airborne threats.

- Ballistic Missile Defense - Ballistic missile defense based on missile interceptors can be saturated by large numbers of warheads. Ponder the consequences of a leak-proof ballistic missile defense--one that could not be overcome by projected numbers of missiles.
- Air Vehicles - Airborne systems of all types, especially those that emit electromagnetic signals, are vulnerable to detection and destruction by enemy ground-based air defenses and airborne interceptors. Ponder the consequences of air vehicles that are capable of countering enemy electronic countermeasures, assure penetration of air defenses, and denial of interceptor attack systems.

Sometime in the future, the foregoing initiatives can be ours instead of the Soviet's. While difficult technical problems remain, the technology is on the horizon and amenable to an investment in well structured, focused programs. You, the members of this Committee, are in effect our investment bankers. In such a position, it seems to me that I must provide you with answers to the following questions:

1. What are we trying to do?

2. What is unique about our approach?

3. Assuming we are successful, what difference will it make?

4. How much will it cost and what are the key milestones?

Last year I presented to you our investment strategy and our major thrusts in space defense, anti-submarine warfare, undersea and armored vehicles, command and control, technology focused on innovative cost reduction concepts, and our endeavors in seeding new efforts. These major thrusts form the backbone of that strategy. I would like to develop further the answers to the foregoing questions in light of events of the past year and relate to you our expectations for FY 1978 and beyond. In brief, we have followed our long-range plan and have impressive progress to report.

A. DARPA Program Plans and Progress

1. High Energy Lasers in Space Applications

Almost from the inception of the high energy laser, people have speculated on the possibility of deploying them in space. This was simply unrealizable using the gas dynamic laser (the first high energy laser) or the electrically excited laser because of their size and weight. Our recently completed analysis indicates that laser systems incorporating much more efficient future chemical lasers may be feasible.

The high energy laser in space, is a potential system to defend our own satellites against anti-satellite threats. The technical problems are formidable, requiring major advances in chemical laser devices; precision pointing and tracking; and large, high-power optics. Nevertheless, space is a favorable environment for chemical lasers. The pressure recovery problem that terrestrial and airborne applications must face does not exist in the vacuum of space, nor are there propagation problems due to the atmosphere which can distort the beam and lessen its effectiveness.

The DARPA program is attacking important aspects of the space-based high energy laser problem. It is my belief that the high energy laser in space could represent a Sputnik-like event....a technical achievement which could influence the perceptions of foreign countries as to who is the leader in defense-related technology. Such perceptions could have serious political implications in view of more obvious trends in other areas. We are requesting $24.9 million for our efforts in space-based lasers and related technology in FY 1978.

2. Space Surveillance

We currently have warning satellites that can detect ICBM launches via the relatively strong signals emitted by such missiles. Such systems consist of detectors which are hardwired to a limited amount of processing circuitry in the

satellite. The information is computer processed to reveal a missile launch signature in the presence of a huge amount of extraneous, noise-like information. The current system, however, is somewhat limited in its ability to detect signals.

We believe that we have discovered two technological breakthroughs that could, in the coming decade, enable us to deploy a single system featuring millions of detectors together with on-board processing to ease the need for wideband data links. Such a system would have the capability not only to detect launches but also many other targets.

The technological breakthroughs which make this possible are:

- The extension of silicon integrated circuit technology, the technology which gave us the pocket calculator and the digital watch, to incorporate both signature detection and signal processing on the same chip via monolithic, silicon, charge-transfer device technology.

- The use of adaptive optics enables us to compensate or fine-tune components of an optical system via selective distortion of portions of a mirror. In effect, one has a "rubber" or deformable mirror which can compensate in real time for mechanical or thermal distortions of optical systems. Such a system can also compensate for the effects of atmospheric turbulence which severely limits the imaging capability of ground-based space object identification systems.

We have structured a program using a high altitude aircraft to gather critical target and background data. These flights, which are scheduled in FY 1977 and FY 1978, will

demonstrate in a field environment a multi-element sensor array and adaptive spectral filters. We are currently initiating a satellite-based experiment, scheduled for February 1980, to provide a proof-of-concept demonstration from space of the detection of weak targets.

Under a project called HALO (High Altitude, Large Optics) we hope to extend the application of silicon technology to allow fabrication of a chip containing thousands of detectors with associated on-chip processing circuitry. This will serve as the basic building block for the ground-based demonstration of a future multi-mission sensor system. In FY 1978, in addition to chip development, a specific tunable filter approach will be selected based on laboratory demonstration models and construction of a system embodiment will begin. The necessary signal processing algorithms will be selected and further refined in preparation for the ground-based demonstration. We also hope to begin design and component test for an adaptive mirror which is an integral part of the system concept.

Our progress to date has demonstrated:

- A silicon chip containing hundreds of infrared detectors with associated processing circuitry;
- The first scanning, programmable infrared spectral filters; and
- Subscale demonstrations of the adaptive optics concepts.

Our program in space-based warning and surveillance is attempting to establish the basic technology that could, if successful, form the basis for a follow-on program to provide a quantum jump in our warning, crisis management, and deterrence posture. We believe that it is imperative for this country to improve its warning and crisis management capability. Based on my knowledge of Soviet technology in the areas of semiconductors, integrated circuits and computers, I do not believe that they are capable of deploying such an advanced system for at least 15 years. On the other hand, all indications are that their policy is one of war-fighting capability rather than deterrence; hence, their need for such advanced warning and crisis management capability is substantially less than ours.

In the area of ground-based space object identification, we will continue the fabrication of an advanced visual charge coupled device focal plane array and the associated adaptive mirror for installation at our Maui observatory. We believe that this will lead to a substantial improvement in our ability to locate and track satellites.

We are requesting $52.9 million for our overall space surveillance efforts.

3. Undersea Vehicles

Drag is a fundamental parameter in undersea vehicle design because it is the primary determinant of range, speed, and endurance. DARPA has demonstrated ways to lower the drag on

small vehicles by factors significantly below that of conventional designs. Low drag technology may find application in advanced torpedo designs and small submersibles. The ability to build small submersibles based on the DARPA laminar flow drag technology could open up important new missions for the Navy.

During the past year, work has continued on drag reduction and more efficient shapes that did not require payload compromises were investigated. The effect of surface roughness was explored as a function of vehicle design. These tests indicate that surface finish may be the critical parameter which will ultimately establish the practical limit of this technology; hence it will be carefully studied in our future efforts.

DARPA will continue work on the theory of laminar flow vehicle design in FY 1978 and we will assist the Navy in exploring the practicality of extending the technology to manned submarines. A self-propelled laminar flow vehicle will also be designed which uses a closed cycle power source. This experimental vehicle should enable us to gain valuable insights into the practical operation of such vehicles including the effects of vibrations emanating from propulsion units. We are requesting

$7.0 million for our efforts in undersea vehicle technology in FY 1978.

4. Anti-Submarine Warfare (ASW)

The continuously evolving threat which this country faces due to Soviet submarines can be summarized as follows:

- New future Soviet submarines could become as quiet as our own.
- Quiet diesel-electric submarines are still a big challenge.
- The deployment of a longer range missile on the Soviet Delta class submarines means that we must cover much larger ocean areas with our submarine detection systems. In addition, the Soviets can deploy at greater ranges from our existing capability, making detection difficult.
- The Soviet navy continues to expand its operations.

In response to the Soviet threat, the Director of Defense Research and Engineering requested that DARPA initiate a program, called SEAGUARD, to define the limits of ocean hearing and pursue new initiatives in ASW at a rate limited only by our innovativeness. This program is focused in the following areas:

1. Large acoustic array technology. This includes telemetry, hydrophone technology, and deployment/mooring techniques.
2. Signal Processing. Our goal is to develop and demonstrate the utility of new processing techniques including acoustic array processing, automatic search, detection, and recognition.
3. Ocean Hearing. We hope to establish the spatial and temporal statistics of the ocean

as an acoustic medium and determine the limits of array performance.

Our present ASW systems have capability against current submarines but are limited in their ability to detect very "quiet" submarines such as those that the Soviets could deploy in the future. Furthermore, when we detect a submarine, localization and target engagement require further search by airborne ASW systems. One of the goals of the DARPA program is to not only detect quiet submarines at long ranges but to localize and track them in real time.

DARPA has found that acoustic signal propagation in the ocean is far more coherent than we had previously thought. This means that we may be able to now employ techniques such as spatial filtering of noise signals and signal processing which have been highly developed in the radar and seismic communities, but had not been considered suitable for use in submarine detection. Among the key remaining issues are quantifying the degradation caused by target or receiver motion and the range and frequencies at which high array gains are practical.

During the past year, DARPA conducted an experiment to demonstrate array techniques. As an integral element of this experiment, DARPA assembled as part of our Acoustic Research Center eight different computers linked via secure ARPANET technology to form the nucleus of the most sophisticated,

advanced, and capable acoustic signal processing facility in the world. The ability to localize submarines to relatively small areas was demonstrated. In FY 1978, we intend to enhance the capability of the Acoustic Research Center to make it more amenable to regular experimentation using data directly from sensors. Experimentation will continue on advanced signal processing techniques using this facility. We will also continue the development of an experimental acoustic array which will have the versatility to investigate potentially useful candidate deployment strategies. Investigation of low frequency active systems, mobile/mobile array correlation and mid-frequency array work will also form part of the FY 1978 program. We are requesting $24.0 million for our ASW efforts in FY 1978.

5. Land Combat

Under this major thrust category we are pursuing a number of initiatives to achieve revolutionary solutions to critical problems expected to be encountered in the land battle of the future. One of the principal efforts is an armored vehicle concept. Just as drag seems to be a fundamental parameter in undersea vehicle design, the size of the gun seems to be a fundamental parameter in armored vehicle design. This follows from the fact that the size, weight, mobility, agility, and cost of a vehicle are closely linked to the size and trunnion reaction of the gun that it must carry. We have been pursuing a revolutionary concept in anti-tank guns---a hypervelocity, medium caliber,

anti-tank machine gun which fires at the rate of almost two rounds per second and has a trunnion reaction that is over 30 times less than the current 105mm guns. The solid propellant version has fired in the burst mode and, using a long rod penetrator of advanced design, it has successfully penetrated heavy armor.

We are well aware that light weight tanks have historically not fared very well on the battlefield. This, we believe, has been due in part to a lack of true killing capability against larger vehicles, poor tactics, and poor survivability. We are attempting to understand the tradeoffs among mobility, agility, armor protection, crew size, and fire control that our 75mm anti-tank "machine gun" may make possible in the future. For this purpose, two test vehicles are under design in a joint DARPA, Army, and Marine Corps effort: one in the 15 to 21 ton class and one in the 30 to 40 ton class. These will enable us to evaluate the impact on fighting capability and survivability of high horsepower-to-weight ratios; advanced transmission and propulsion concepts; tank automation; the level of fire control sophistication; and the medium caliber, hyper-velocity, rapid fire anti-tank gun. We expect to begin full parametric testing of these concepts in FY 1978.

DARPA initiated this systems testbed approach to armored vehicle design in FY 1976. In FY 1977, we developed a

formal mechanism for joint DARPA, Army. and Marine Corps funding and management, with the objective of phasing out DARPA involvement by late FY 1979. We are requesting $10.9 million to accomplish our armor-related efforts in FY 1978.

6. Command and Control

The key to effective utilization of our forces is command and control. It is perhaps the ultimate force multiplier--a statement which is acknowledged by practically everyone. Why, then, do we seem to have so much difficulty coming to grips with the problem? Speaking as a technologist, and putting aside those aspects of the problem which deal with physical survivability, jamming, and spoofing threats, I would characterize the problem as follows:

- The technology base for modern command and control is incomplete. Filling the gaps requires a synergistic relationship among computer science, communications and information sciences. Unfortunately, most of the people involved in the problem gained experience in the communications community and tend to think about C^3 in a one-dimensional framework.

- No testbed is used for C^3 experimentation; consequently, decisions are based on insufficient data, the best of candidate architectures is not possible, and system issues are not resolved in "try-before-buy" fashion.

- The gap between the system engineer and the operational user is perhaps larger in the C^3 area than any other application area. This leads to system designs that are largely insensitive to user's desires and which substantially ignore unique needs of the human interface.

The approach of the problem suggests the ingredients of our unique three-part attempt to its solution:

1. We are filling the gaps to provide an adequate technology base for C^3.

2. We are establishing a testbed in which C^3 technologies and system designs can be evaluated in a "try-before-buy" fashion.

3. We are using the testbed to assess the cost effectiveness (including real-world applicability/utility) of advanced C^3 technologies.

We are directly addressing user needs and problems by demonstrating new system designs in the testbed in order to solicit user feedback based on hands-on experience with new system designs and by developing and evaluating new principles of design for the human interface in C^3 systems.

Filling the gaps to provide a technology base for modern command and control demands several unique technical initiatives:

- A cornerstone of advanced command and control is communications. We are extending the proven technology of the ARPANET to packet switching in a satellite communications environment; to packet radio, aimed at bringing the power of the ARPANET technology to the mobile, distributed user in a secure, jam resistant manner; to speech communication in a packet communication system; and to teleconferencing and advanced automated message handling capabilities.

- Complex decision making at high speed, under stress, during crises requires automated decision aids for users as part of the C^3 system design. We are laying the foundation of an advanced decision technology including aids for decision making, reasoning, and

problem solving by individuals and heterogeneous groups.

- The key to good decision making is the availability of essential, timely, and accurate information. We are filling the technology base gaps in the area of distributed automated data base management, essential to survivability in C^3, and in data base management problems unique to very large amounts of information--questions of data verification, data base search strategies, and data base organization.

- C^3 systems must be both secure and cost effective. In the past, security has been achieved at the expense of cost effectiveness because of technology limitations. We are overcoming those limitations to provide new capabilities for multi-level secure computer and network systems.

We are working with the Navy to implement a testbed for test and evaluation of C^3 technologies. One doesn't design aircraft without a wind tunnel or ships without a tow tank; hence, we believe that a C^3 testbed is needed. It will serve as the integrating function and "final exam" for modern, expensive C^3 technologies.

- The testbed is realistic in its hard and soft failure characteristics; in its distributed geography; and in its use of varied hardware. It will include capabilities for use in exercises with repeatable, automated crisis simulators. Realism is an essential component in the testbed design if evaluation results are to be believed and used.

- The testbed will be broadly reconfigurable so that a variety of competing technologies can be assessed, including technologies for natural language communication with C^3 data bases, multi-level security, automated message handling, and so on.

- The testbed will incorporate new technologies for C^3 performance measurements so that we can achieve an objective assessment of the value of C^3 technologies based on practical experience rather than abstract theory.

Problems of the human user of C^3 systems are being directly addressed in two ways:

- New system designs configured in the testbed will be tried by users under realistic circumstances and their feedback will influence system design in an iterative fashion. Scenarios which we are considering include search and rescue, ocean surveillance, and surveillance avoidance, among others. Tightening the loop between system designers and users will significantly reduce the mismatch between C^3 systems desired and C^3 systems delivered.

- New design principles for the human interface in C^3 systems are being developed and tested based on advances in computer science, human factors engineering, and psychology. Our activities are leading to natural language interfaces for data bases which will enable individuals to use computers in a way that doesn't require detailed familiarity with computer languages and procedures; new information storage and retrieval systems that complement, rather than conflict with, human memory structures; and new methods of information selection, presentation, structuring, and pacing.

In FY 1978, our advances in C^3 technology and C^3 user interfaces will be extended to a fully operational C^3 testbed for evaluation and selection. We are requesting $23.2 million for our command and control related efforts in FY 1978.

7. <u>Lowering the Cost of National Defense Through Technology</u>

It is not sufficient in this era of tight budgets that technology be focused exclusively on improved performance.

We do not feel, however, that it is our mission to apply ourselves to the more obvious ways that this can be done which involve straight-forward application of existing principles. Instead, we are investigating high-risk areas with the potential for major impact that require the development of entirely new technologies. An example of this approach is our work on ceramic turbines. The efficiency of gas turbines is determined in large measure by the operating temperature. Our highest performance engines require costly and scarce materials called superalloys to operate at temperatures of about 2200^{o}F. In addition, superalloys are difficult and costly to machine. It is estimated that it costs $55 per pound to machine such materials and, for each pound of engine, we must leave seven pounds of chips on the floor. Ceramics offer the potential of a revolutionary breakthrough in cost and performance because they are not only inexpensive, readily available and easy to fabricate, but also promise higher (2500^{o}F) operating temperatures; hence, greater performance, smaller size, cleaner operation, and lower specific fuel consumption.

Our vehicular ceramic turbine program is now a joint program with the Energy Research and Development Agency (ERDA). During this past year, we have demonstrated the capability of an integrated ceramic rotor to operate for short periods of time at turbine inlet temperatures of 2500^{o}F and speeds up to 65,000 RPM. Our Marine ceramic turbine (1000 horsepower effort) is on

schedule with a demonstration in a patrol boat scheduled for late FY 1979.

Another example of how we apply the "quantum jump" approach is in the area of non-destructive testing. This is an area that is becoming increasingly important due to our use of new materials and the stress engendered by mission demands. Current non-destructive test and inspection techniques are not quantitative; hence, we are forced to adopt an expensive "zero defects" philosophy. This is the case because we have not been able to quantify the effect of a defect or directly relate it to performance.

Because of the importance of the problem and its potential for cost reduction, we have initiated work in quantitative non-destructive testing. Technology must be developed to enable us to build-in specific types of defects and evaluate their impact on performance. In addition, we must learn how to catalogue the "signatures" of such defects so that they can be compared to measured signatures obtained from real parts. This is high-risk research requiring the development of new technology and new applications of the principles of physics. It has proven challenging, but the potential payoff is so great that the challenge must be accepted.

These are but two examples of how we apply the DARPA revolutionary approach to new technology to the major

problem of cost reduction. Others include mini-RPVs, distributed sensor systems, "hands-off" vehicular diagnostics, unique materials design and processing methods, and innovative computer based training concepts. We are requesting $24.0 million for technology efforts focused on cost reduction in FY 1978.

8. Laying the Groundwork for Future Technological Revolutions

While DARPA has prioritized its program into six major thrusts that we believe will have a major impact on national security in the 1980's, we will continue to be the spawning ground for innovative ideas that have the potential to grow into programs of major impact. Let me give you a few examples:

- We are exploring the fundamental limits of the technology of autonomous terminal homing. We believe that if the accuracy of cruise missiles can be increased, many missions, both tactical and strategic, that currently require nuclear warheads could be accomplished with conventional warheads. Success in our efforts could perhaps lead to an increase in the nuclear threshold....a stabilizing factor.

- We are exploring concepts that could lead to air defense systems which do not reveal their presence due to emissions from their colocated radars. Such systems would deny the enemy the use of his electronic countermeasures and anti-radiation missiles.

- We are pursuing advanced missile and undersea target acquisition concepts that could enable a submarine to protect itself against airborne surveillance threats such as those extensively employed by the Soviets.

- We are linking biocybernetics technology to computer-based training and flight training simulators in search of a breakthrough in man/machine interactions.

- We are developing compound semiconductor process technology that will make possible integrated circuits that will far surpass existing silicon-based circuits for achieving high data rate signal processing necessary for future high-resolution surveillance and tracking applications.

- We are breaking new ground in the field of rapidly solidified (10^5 to 10^6 degrees per second cooling rates), submicron-particle metals. Success in our work could lead to entirely new metallic microstructures with tailored properties, and possibly extension of this technology to semiconductor and ceramic materials.

- We are attempting to develop new methods for the detection and localization of deep tunnels.

- We are attempting to apply machine or computer intelligence to problems in electronic warfare, ASW, and morse code reading. These tasks require special skills and are manpower intensive at the present time.

The foregoing should illustrate that we in DARPA continue to seek out and exploit innovative, high-risk technologies which have the potential to enhance national security in major ways.

B. Some Aspects of Program Implementation

During the past several years you have been alerted to the tremendous Soviet drive to seize the technological initiative as well as gain superiority in deployed military equipment. I don't like the trends, and I am somewhat overwhelmed by the sheer

magnitude of the Soviet effort. But I think there is another question to be asked and that is crucial for all of us: "What are we doing that can make a major difference?" I believe that the DARPA program and investment strategy focus on that question and have some solid answers. The Secretary of Defense and the Director of Defense Research and Engineering have demonstrated their conviction and support of our initiatives by requesting a $45.0 million increase in the DARPA budget for FY 1978. Of this increase, $17.0 million will be used to cover inflation costs. This increase is needed because of three factors:

- The recognition that the DARPA program is focused on answering key questions that could become the national security issues of the 1980's.
- The recognition that the DARPA program contains initiatives that could have a major impact on our security.
- The expressed need to work out the risks of innovative technology before major system commitments are established by the Services.

The last point is worthy of special note in that we are requesting $34.0 million in FY 1978 for major, high-risk, proof-of-concept demonstrations in the areas of space-based infrared surveillance, new aircraft and armored vehicle concepts, submarine self-defense, ceramic turbines, and command and control. These are programs for which the initial groundwork and feasibility were established by our previous efforts. With the strong support of the Director of Defense Research and Engineering and the

Services, we are attempting to logically extend the innovative, high-risk/high-payoff technology which we have pioneered so that the Secretary of Defense, the Director of Defense Research and Engineering, and the Services have a more meaningful assessment of its impact and associated risks before major programmatic shifts and commitments are made.

The question is often asked, "Why shouldn't we just stretch things out or fund at a "level of effort?" I believe that we have funded things in the technology base at a "level of effort" for too long. We need to take the initiative, and that requires prioritization and imaginative, high-impact programs. I have outlined an investment strategy that offers unique potential for major impacts on national security. We have prioritized our efforts and internally reduced 21 programs by $16.0 million and have transferred 17 programs to the Services in the past year. We have responded to requests from Congress that we eliminate work in the areas of manpower studies and broader studies of a policy nature. In view of these actions, I do not believe that it is either cost effective, practical, or wise to stretch out exciting programs with the potential for major impact. Stretch-outs usually mean that results are promised but rarely delivered and the transition to the Services is haphazard at best. Furthermore, the motivation, excitement, and incentive of "final exams"

are diffused, decision making is discouraged, and institutionalization generally results.

We also sometimes hear the refrain, "Why don't the Services do what DARPA is doing?" There is a combination of reasons that may apply in any given case which forms the basis for our programmatic selection process:

- The Services, faced with tight budgets and broad requirements, often found that there were too many "today" problems requiring immediate solution or quick fixes to give adequate attention to high-risk future horizons.

- Because of the difference in perspective, the Services did not get the idea or recognize its potential, or the program fell between Service lines.

- The program required an investment where risk was deemed too great for Service support.

- The Secretary of Defense wanted an outside examination of a program which could represent a significant departure from an ongoing system development in a Service.

- The program did not fall within traditional roles and missions of the Services, or a traditional area needed "shaking up" from outside its own bureaucracy.

- The Secretary of Defense or the Director of Defense Research and Engineering wanted to investigate some new ideas without implying an eventual commitment to production.

DARPA is built around people, ideas, and organizational flexibility. I have discussed our program and the organizational flexibility which is fundamental to its formulation and implementation. Now I would like to tell you about the people. DARPA is a lean organization--a staff of only 89 civilian and military

professionals to execute a diverse $280.5 million program. Our manpower is 32% less than it was ten years ago when our budget was about the same as our FY 1978 request. Our administrative costs are less than three percent of our total program. We are staffed with highly motivated individuals who focus on challenges and who are not content with the status quo. Our people change as our technology thrusts change and are usually in DARPA for less than four years. Typically, we attract people with a record of solid achievement in industry, academia, government, or the military. We recognize our role in the DoD, and we carefully focus and prioritize our efforts and couple them with meaningful "final exams" so that only the most important programs are transitioned and executed. We are not in the business of institutionalizing programs.

C. In Conclusion

Recognizing that more detail can be found in the bulk of my statement, I hope that in a preliminary way I have addressed to your satisfaction the key investment questions:

1. What are we trying to do?
2. What is unique about our approach?
3. Assuming we are successful, what difference will it make?
4. How much will it cost and what are the key milestones?

We may not be successful in all our efforts, but success in only a few of our major thrust programs could make a major difference in national security. That's a high return on an investment when you consider that for FY 1978 it represents only 12% of the Department of Defense budget for the technology base and two percent of the total RDT&E budget.

The details of our FY 1978 program and our past year achievements can be found in the statement which follows.

II. THE DARPA PROGRAM - FISCAL YEAR 1978

The budget requested to support the DARPA program I have just outlined represents an increase of \$45 million over the FY 1977 approved program. The funds requested will permit a 13% increase in effort in non-inflationary dollars over our FY 1977 program, which I believe is essential if we are to exploit and extend technological gains made in recent years. This is particularly true in space surveillance, high energy lasers, and strategic deterrents (autonomous terminal homing and unconventional defense). You will note in attached table a substantial increase in our Strategic Technology element in these projects. In addition, as I previously indicated, we have included a new program element which consolidates our on-going efforts in support of vitally important proof-of-concept and qualification of payoff measurements and experiments. These critical efforts are based on research results from previous years' efforts which must now be applied in sufficiently mature experiments or testbeds to measure their true utility before the major commitments, which full-scale development will require, are made. I firmly believe the funds we are requesting in this element for experiments to evaluate emerging technology, analogous in many respects to test marketing in the private sector, represent one of the most productive investments we can make. Modest increases are also being requested in our basic research element to permit new initiatives in advanced geophysical concepts and revolutionary detection research. We cannot afford to continue to draw on our current levels of knowledge in these pivotal areas. While we continually explore new ideas and

restock our store of knowledge in all areas, these two are of particular concern.

I believe that, from an overall viewpoint, the budget we are requesting will allow us to establish and carry out a carefully conceived research and exploratory development program that is responsive to critical long-term national defense needs. The proposed program provides a balanced allocation of resources to: (1) foster new "seed" efforts in emerging technological areas; (2) stimulate growth of technological "saplings" that have proven promising; and (3) harvest those technologies that have become mature "trees." These three categories represent 18.8%, 61.2%, and 20%, respectively, of our FY 1978 program.

The following table, extracted from the Justification of Budget Estimates and separately submitted, shows the distribution of our budget request by program element and subelement for FY 1978. I have also included actual funded expended in FY 1976 and estimates for FY 1977. For the record, the following sections portray a more extensive statement on the status of ongoing programs and future plans. In Section III, some of the more significant DARPA achievements during the past year are listed.

A. SUMMARY OF FUNDING ($ in thousands)

Program Element	Title	FY 1976 Actual	FY 1977 Estimate	FY 1978 Estimate	FY 1979 Estimate
61101E	DEFENSE RESEARCH SCIENCES	$33,232	$36,195	$42,100	$52,900
	MATERIALS SCIENCES	$14,957	$16,240	$16,900	$21,200
	Advanced Systems Materials	4,649	4,850	4,860	7,600
	Electro-Optical Materials	10,308	11,390	12,040	13,600
	CYBERNETICS SCIENCES	$ 2,656	$ 2,500	$ 3,400	$ 3,900
	COMPUTER AND COMMUNICATIONS SCIENCES	$15,619	$16,755	$18,800	$22,300
	Image Understanding	3,252	3,212	3,232	3,350
	Intelligent Systems	8,020	9,092	8,346	6,800
	Advanced Network Concepts	-	717	2,537	5,350
	Advanced Digital Structures	4,347	3,734	4,685	6,800
	ADVANCED GEOPHYSICAL CONCEPTS	$ -	$ 200	$ 1,000	$ 2,000
	UNCONVENTIONAL DETECTION RESEARCH	$	$ 500	$ 2,000	$ 3,500
62101E	TECHNICAL STUDIES	$ 2,300	$ 2,300	$ 2,500	$ 2,700
62301E	STRATEGIC TECHNOLOGY	$68,284	$76,180	$82,700	$94,800
	Advanced Strategic Concepts & Strategic Technical Analysis	2,098	2,180	2,454	2,505
	Space Surveillance and Advanced Optics	7,786	19,010	25,266	27,504
	High Energy Laser Technology	20,860	21,100	24,853	25,175
	Strategic Deterrent	4,334	4,555	7,349	13,770
	Air Vehicles	1,756	1,758	1,684	2,632
	Warning Technology	10,602	8,834	6,527	10,571
	Special Applications Technology	4,953	4,613	4,045	4,872
	Space Object Identification	15,895	14,130	10,522	7,771

Summary of Funding ($ in thousands) - Cont'd

Program Element	Title	FY 1976 Actual	FY 1977 Estimate	FY 1978 Estimate	FY 1979 Estimate
62701E	NUCLEAR MONITORING RESEARCH	$14,009	$12,480	$10,500	$ 7,000
	Seismic Verification	8,295	7,930	7,650	5,700
	Nuclear Diagnostic Techniques	1,444	1,110	580	200
	Threshold Test Ban Treaty Yield Verification & Counter Evasion	1,605	3,025	2,250	1,100
	Underwater Acoustic Research	1,355	-	-	-
	Energy Information	300	-	-	-
	Geodesy & Gravitational Research	1,010	415	20	-
62702E	TACTICAL TECHNOLOGY	$54,163	$66,470	$69,600	$81,800
	Target Acquisition & Engagement	18,023	25,311	26,883	31,450
	Weapon Technology & Concepts	11,005	17,057	11,272	15,650
	Ocean Monitoring and Control	25,135	24,102	31,445	34,700
62706E	DISTRIBUTED INFORMATION SYSTEMS	$11,701	$ 8,345	$ 9,100	$10,000
	Software Technology	3,857	3,051	2,998	2,198
	System and Network Security	-	1,788	2,236	2,637
	Speech Processing	5,800	3,007	3,256	3,846
	Distributed Sensor Networks	-	184	610	1,319
	Parallel Processing App	313	315	-	-
	Climate Dynamics	1,550	-	-	-
	Distributed Networks	181	-	-	-
62708E	ADVANCED COMMAND, CONTROL AND COMMUNICATIONS TECHNOLOGY	$ 8,238	$ 9,470	$10,400	$12,500
62709E	SYSTEMS CYBERNETICS TECHNOLOGY	$ 8,210	$ 6,871	$ 7,400	$ 8,100
	Military Cybernetics	6,068	4,420	4,750	5,350
	Cybernetics of Instructional Systems	2,142	2,451	2,650	2,750
62711E	EXPERIMENTAL EVALUATION FOR MAJOR INNOVATIVE TECHNOLOGIES	$ 2,314	$ 2,899	$34,200	$37,900
	Cermaic Turbine Experiment			3,200	2,700
	Teal Ruby Experiment			9,500	7,900
	Experimental Aircraft, X-Wing, HIMAG, SIAM Testbeds			18,000	21,200
	Advanced Command Control Architectural Testbed			2,500	3,400
	Technology Assessments	2,314	2,899	1,000	2,700

Summary of Funding ($ in thousands) - Cont'd

Program Element	Title	FY 1976 Actual	FY 1977 Estimate	FY 1978 Estimate	FY 1979 Estimate
62712E	MATERIALS PROCESSING TECHNOLOGY	$ 7,500	$ 9,890	$ 7,300	$10,000
65803E	PROJECT MANAGEMENT SUPPORT	$ 4,059	$ 4,300	$ 4,700	$ 4,682
	Total ARPA	$214,010	$235,400	$280,500	$322,382

B. Major Thrust Projects and Tasks

The sections that follow are intended to provide more details on key efforts in our major thrust programs. In each case, the prime objective, current status, and plans for the future are described. Finally, estimates of the payoff in terms of new mission initiatives, increases in current operational capability, or means for significant cost reductions are provided.

1. High Energy Lasers in Space

The trend of US and Soviet military posture is towards an increasing use of space as an operational environment and an increasing reliance on satellite-based systems. Accordingly it is important to identify and assess concepts and related technologies which are uniquely suited to space. Because space has no propagation restrictions, the major unique property of a laser can be fully utilized—the ability to precisely concentrate energy at extreme distances with the speed of light. The DARPA program is dedicated to developing the critical technologies required to demonstrate the feasibility of laser system technology for these space-related applications.

The major thrusts of this program are: (1) the development and demonstration of device technology for both space-based infrared hydrogen-fluoride chemical lasers and ground-based visible electrically-excited lasers; and (2) the development of optics and precision tracking and pointing technologies for space-related applications.

For applications requiring lasers in space, the infrared (2.7 um) hydrogen-fluoride chemical laser is the most promising device candidate because of its high power per unit system weight. During the past year our goal of demonstrating useful efficiencies was reached in a small-scale device. The program during the next year will address the problems of scaling.

Visible lasers offer significant advantages over the infrared hydrogen-fluoride device because of optical system design

penalties imposed by longer wavelengths. The single pulse energy of ultraviolet-visible lasers was scaled from 1 joule to over 300 joules in the last year.

One of the pacing technical problems in developing a high-power, ultraviolet-visible, noble gas, eximer laser system is the development of mirrors and windows for control of the laser beam. During FY 1977 DARPA started an effort to develop materials for dielectric-enhanced mirrors, antireflection coated windows, and other critical optical components for the eximer lasers. The laser pulses are so intense that antireflection and reflection-enhancement coatings are frequently blown off with a single laser pulse. If they are not, the components may optically distort and defocus the laser beam during the one microsecond duration of the laser pulse. Operating optical components under repetitive loads of this magnitude requires withstanding significant long-term thermal loads in addition to the pulse loading. Our objective in this research is to achieve order-of-magnitude improvements in component performance.

In the all-important area of optics for space-based systems, studies have been initiated to explore the feasibility of reflecting optical structures in space with low figure error tolerances. To take advantage of the long-range potential of such optics, ultra-precision tracking and pointing systems are required. Recently, precision tracking of a space object was demonstrated using a laser radar.

We are requesting $24.9 million for FY 1978 to continue these major thrusts. We propose to establish the scalability of the hydrogen-fluoride chemical laser technology. We propose to increase ultraviolet-visible single pulse energies while initiating flow and power developments to allow repetitive pulse, high power operation. Development of the technology base for optical structures will be continued. Completion of the installation and integration of components into the previously developed infrared laser radar is expected during FY 1978. This will lead to a capability to demonstrate high precision, long-range tracking of space objects.

2. Space Surveillance

The DARPA program in this major thrust area is addressing both passive and active techniques. While emphasis is being placed on passive systems because of their obvious low signature advantage, they cannot observe through all weather and in some low visibility conditions. Active techniques are being pursued to provide all weather day/night capability, but with special emphasis on minimizing the inherent detectabilities of an active system.

a. Passive Space Surveillance Techniques. All military targets have signatures. These signatures range in signal strength from millions of watts to a few tens of watts. Some targets may produce less than a single watt. The purpose of the space surveillance activities at DARPA is to develop and demonstrate new surveillance sensor technology which will protect warning capability. The detection of military targets is complicated by the presence of the energy radiated from the earth, its atmosphere, and stars. This energy imposes a background clutter that obscures dim targets. The fundamental task of advanced surveillance sensors is to overcome the masking of targets by this background clutter while maintaining the high search rate required for strategic surveillance.

To insure that the proposed technology is developed and that the future prospects for surveillance are fully explored, it is necessary to understand the characteristics of

military target signatures and the backgrounds against which they have been observed. DARPA has completed a program to characterize space backgrounds and the signatures of targets. Simultaneously we are making, for the first time, measurements of the background against which these targets are observed. We are requesting funds in FY 1978 to complete these critical measurements.

The DARPA program combines several techniques for achieving detection of very weak targets immersed in background clutter.

- A small field of view is used for each detector so that a minimum of background noise is included with the target signal. Maintaining high search rates over large areas with a small field of view for each detector requires very large numbers of detectors operating in parallel.
- Filters are used to enhance the differences between the radiation from targets, and that from natural backgrounds.

Based upon the success we have had to date with laboratory demonstrations of the new technologies of CCD visible arrays and adaptive optics systems, and based upon the data

obtained to date on targets and backgrounds, we are undertaking the development and demonstration in a field environment of selected technologies. I would like to briefly describe three critical experimental demonstrations that we are currently working toward.

(1) Ground-Based, Rapid Search Demonstration. Currently available technology in radars and electro-optical sensors can only marginally improve the ability of the US space tracking system to perform search at reasonable cost. In FY 1978 DARPA will construct the first fully integrated sensor for ground-based space surveillance. This sensor will contain CCD detectors and will demonstrate the CCD^2 clutter rejection processing necessary for future space sensors. Field tests of the sensor will be carried out in FY 1979 at DARPA's Hawaii station.

(2) Compensated Imaging Demonstration. A large telescope of 60-inch diameter like the DARPA telescope in Hawaii should be able to see detail. Instead, the atmospheric turbulence limits resolution to three to six feet. The image degradation caused by atmospheric turbulence changes hundreds of times each second. Adaptive optics can operate very quickly to continually measure this image degradation and deform flexible mirrors to correct it. DARPA has developed concepts and demonstrated components useful for rapid measurement and correction of image degradation due to atmospheric turbulence. Currently a compensated imaging system is being

constructed for the DARPA 60-inch telescope. In FY 1978, this system will be completed and in FY 1979 it will be field tested in conjunction with the ground-based space surveillance sensor. This program should provide a convincing demonstration of the power of real-time adaptive optics.

(3) Detection Demonstration. One of the most significant implications of this next generation of surveillance system technology is that it may be possible to combine many functions into a single system. To achieve this multimission capability, DARPA has initiated a project called HALO which stands for High Altitude, Large Optics. This concept requires large improvements in the state-of-the-art of all of the new technologies under development by DARPA for surveillance--CCD's, signal processors, and lightweight optics. We have identified the levels of component performance required for this concept to be feasible and have initiated developments which will culminate in substantive ground-based proof-of-concept demonstrations. Let me briefly describe our program goals in the areas of focal planes and lightweight optics.

Focal Planes. Charge coupled device technology will allow tens of thousands of detectors to be manufactured in single, integrated chips. These small chips can then be packaged into focal planes required to detect very small signals while rapidly searching large areas. This technology allows a large number of detectors to be built at low cost compared with current technology.

In order to establish the feasibility of extending the size of mosaic focal planes, we are increasing the size of

individual array chips and increasing the degree of signal processing integrated into the array.

The ability to sense dim signals can be enhanced if the intensity of the radiation from the target varies with wavelength in a different manner than that of the background radiation. In such cases, spectral filters can be used to block much of the background noise and pass radiation characteristic of the target. In addition to increasing the detector array chip size, DARPA is also developing filters to allow their use over these larger focal planes. Demonstration of these components will allow an integrated demonstration module to be built and exercised.

An important additional benefit to surveillance systems from CCD technology is the ability to integrate charge coupled device signal processing into the charge coupled device imaging chip. We have called this concept the CCD^2. Integration of signal processing and detection functions on the same chip allows the processing necessary to extract targets from clutter to be performed automatically within the focal plane. This eliminates the cost and time delay associated with the use of large, ground-based computers for clutter suppression. A demonstration of CCD^2 operation has been accomplished on a testboard using a visible CCD imager and a CCD memory. The performance was sufficient to allow the detection of faint satellites against the star-studded space background. A CCD^2 device has also been operated with the detector array and memory integrated in to the same chip.

<u>Lightweight, Adaptive Optics.</u> In order to achieve the sensitivity to detect dim targets from high altitudes,

a radical departure from traditional optical manufacturing technology is required. DARPA has initiated a program to develop a new optics technology to provide lightweight, modular mirrors and structures that lend themselves to a more rapid manufacturing capability.

Lightweight optics will be achieved by employing thin glass or metal membrane faceplates on high stiffness-to-weight ratio supporting structures. In addition, adaptive optics will be employed to acquire and maintain the optical figure quality on the mirrors that are required for precision imaging.

In FY 1977 the baseline optical designs for large diameter, short focal length telescopes were completed and a lightweight mirror was fabricated with graphite/epoxy materials. In FY 1978 all optical design work will be completed, additional demonstration mirrors will be fabricated, and the sensors required for deriving error signals for the adaptive control systems will be completed. A model of a full-scale telescope employing lightweight mirrors with adaptive figure control will be demonstrated.

The focal plane and lightweight optics technology to be developed under the HALO program will form the basis for a revolutionary surveillance system capability. This technology is expected to have a profound effect on the United States strategic posture. In addition, the application of large-scale focal planes and space-based adaptive optics may have tactical applications. DARPA has developed new concepts for surveillance using geostationary satellites. These platforms may have the capability of providing

simultaneous, continuous observation of large areas. DARPA is currently refining this concept and establishing in detail the required levels of technology. In FY 1978, we expect to initiate development of technology that is uniquely required for the surveillance system.

b. Active Space Surveillance Techniques. Since FY 1975, DARPA has been engaged in advanced research leading to the development of active surveillance technologies which improve target detectability. To this end, the use of spaceborne radars with large apertures have been evaluated. Based on measured target and clutter data, this concept has been shown to provide effective surveillance. The concept, which is applicable to any radio frequency wavelength, is being used by the Air Force to define and evaluate future spaceborne radar systems. In FY 1977, the concept of spatial diversity will continue to be expanded to address the potential of using a radar to satisfy not only major surveillance requirements (i.e., detection of strategic targets), but for electro-optical sensors as well. Based on previous analyses, the basic issues to be addressed in FY 1977 and 1978 are how to provide high resolution while employing the minimum number of transmit and receive elements.

As part of the overall spaceborne surveillance program, spaceborne radars are also being investigated. Ground-based and airborne experiments are being conducted. High power transmitter technology is being pursued in the laboratory with the aim of

demonstrating useful power outputs. The companion technology of array element designs is also being pursued.

3. Undersea Vehicles

DARPA has pioneered the development and application of techniques for low-drag undersea vehicles. We have demonstrated that careful hydrodynamic shaping reduces the drag of torpedo-sized bodies. This work has matured to the point where the Navy is building vehicles based on DARPA design calculations which will provide at-sea comparison with the data from DARPA's continuing laboratory and tow tank experiments. This year we are testing the feasibility of using a technique to control the friction in the boundary layer, a technique which has few theoretical limitations, but different practical problems than our previous heated body work. We plan to extend our efforts toward optimizing the use of shape to achieve larger low-drag vehicles. A complementary effort is exploring the feasibility of using advanced closed cycle non-nuclear engines to power high endurance low-drag unmanned vehicles.

a. Low Drag Bodies. In order to achieve the required low underwater drag, the fluid flow next to the surface of the body must be controlled to delay or prevent the formation of eddies or turbulence which causes significant increase in hydrodynamic resistance. The maintenance of smooth or laminar flow over a submerged body is a problem of considerable sophistication which is being successfully attacked by DARPA's program of analytical and experimental research. By careful

control of the body shape and detailed attention to surface conditions, we believe that we are approaching the ultimate in favorable conditions. Recent tests indicate that we have achieved a drag less than that of a conventional shape at the same speed. Pop-up tests conducted last year confirmed our theoretical predictions and previous model test results. These tests highlighted the vibration isolation considerations that must be incorporated into laminar flow vehicle design in order that their low self-noise potential may be fully realized. Currently a self-propelled laminar flow vehicle is being tested on a Navy range and will serve as a flow-noise testbed for future Navy acoustic sensor designs.

Last year we demonstrated a laminar flow vehicle. Additional test results, however, are needed before this technology can be optimally applied to torpedo design. Tests are now being conducted on three new body shapes that should resolve the major hydrodynamic issues of the applicability of laminar flow technology to torpedo designs. The technique of sucking a small quantity of fluid through a porous wall has been identified as a promising technique which will be tested early in FY 1978.

A flow-tube (outside-in simulation of large laminar flow bodies is being conducted this year to provide preliminary experimental evaluation of various large body designs. Memoranda

of understanding have been signed by DARPA and the Navy outlining the phased transition of this research program over to the Navy.

DARPA will continue to support a broad range of theoretical and analytical investigations which are continuing to improve the ability to compute the optimal designs of low-drag bodies. The ability to analytically predict the effects of various disturbances (such as roughness and vibration) is an important area for continued research.

b. Closed Cycle Power Sources. Undersea operation precludes ambient air-breathing or open-cycle power systems. A closed Brayton cycle gas turbine engine has been developed and is now under test. This year we have added auxiliary working fluid management and quiet variable speed transmission components to this engine, which are essential for undersea propulsion applications. All of these components are being combined this year for evaluation of the system as a whole. This testbed propulsion system will be transferred to the Navy to serve as a pilot plant for much larger systems that could be used in large submersibles. The Brayton cycle is most beneficial in large power systems.

Existing Sterling cycle engines appear to be attractive for small, compact limited volume applications. Next

year we will evaluate a specific chemically-fueled, closed-cycle Sterling propulsion system for long-range, high-speed applications.

4. Anti-Submarine Warfare (ASW)

The most invulnerable and, therefore, most credible, element of the strategic Triad is the SLBM, since its launch platform, the nuclear-powered submarine (SSBN), is mobile and well-concealed by the ocean. As long as a large portion of the SSBN force can avoid continuous surveillance, a successful pre-emptive nuclear strike is not possible. Continuous surveillance of submarines may only be possible by monitoring either the acoustic energy they radiate or by observing the hydrodynamic disturbances which their motion may induce. The key to avoiding acoustic surveillance is to build quiet submarines. The US has expended great efforts to develop and implement effective noise-quieting technology. This forms the rationale for DARPA's program of ocean surveillance research, development, and experimentation, which is generally directed toward the two key problems of detecting and tracking the relatively weak signals associated with a submarine and processing these signals.

a. Acoustic Signal Detection. At any given time, there are several thousand maritime merchant ships crossing the world's oceans. Each of these ships constitutes a potential source of acoustic interference to our undersea surveillance system. Merchant ships are not designed for quietness, they are designed for economical transport and their high-powered propulsion systems generate a great deal of noise which is well-coupled to the ocean's acoustic propagation path.

The problem in ASW surveillance is to distinguish the relatively weak submarine signals from the much stronger signals associated with these surface ships.

By specific assignment from the Director, Defense Research and Engineering, we are pursuing a highly directed program of research, development, and ocean measurements and experimentation to determine the fundamental physical and technological limits of acoustic detection of submarines. The SEAGUARD program consists of the following elements: development and evaluation at sea of new large aperture acoustic arrays to improve signal detection capability; advanced processor and processing technology to enhance our ability to handle signals once they are detected; and, beginning in FY 1978, research and experimentation in active acoustic surveillance.

Work is underway to determine the relative importance of these effects. As our experimental data grow, we will continue to refine these theories which promise to be powerful predictive tools for the design of advanced acoustic systems.

Last year, I discussed a program which DARPA undertook in conjunction with the Navy from 1972 to 1975 to evaluate the technical feasibility and operational usefulness of acoustic arrays for passive surveillance. The program resulted in the development and evaluation of an array which will be able to counter the effects

of silencing techniques, and its capability will allow it to keep pace with changing operational doctrines. These are important capabilities. For this reason, in FY 1975, DARPA initiated the Ocean Measurements and Array Technology (OMAT) program. In FY 1976, an array and associated signal processing equipment were designed. In FY 1977, the system is being fabricated and the first deep ocean acoustic measurements will be made with this system in the summer of 1978. A new acoustic design is being used in this measurement system which, in addition to having excellent performance characteristics, is only one-fourth as expensive to manufacture as present systems with similar performance. We are developing a deployment technique for this system which should considerably simplify and reduce the cost of deploying future large aperture surveillance array. This deployment technique, which will use standard Navy ships, requires that the array be strong, but lightweight, relative to existing arrays. To meet this requirement, recently developed lightweight synthetic fibers are being used as strength members instead of steel cables and specially molded syntactic foam elements are being used as distributed buoyancy elements in place of heavier plastic elements. The signal processor for this system will permit real-time data reduction so that we will have meaningful results very soon after an experiment is completed and at greatly reduced cost. The processor is compatible with data transmission to the DARPA Acoustic Research Center to permit other kinds of real-time experimentation to be conducted with the array. This processing system will also be capable of handling acoustic data

so that it will be able to support our new initiatives in mid-frequency acoustics and active surveillance.

Beginning in FY 1978, we will expand SEAGUARD. We will develop an array to exploit and will use the signal processor developed in the OMAT program to reduce and analyze the data, thereby saving significant costs in development. We will begin at-sea experiments in late FY 1978 using well-designed arrays to obtain data to support the design.

b. Acoustic Signal Processing. Signals detected by acoustic arrays contain essentially two kinds of information. Typically, a containment probability is associated with these uncertainty areas to allow for the possibility that the source is actually located outside the containment area.

DARPA's program in signal processing research heavily emphasizes the development and experimental evaluation in an operational environment of advanced processor technology and algorithmic techniques, or software, which will greatly reduce the area of uncertainty associated with a given target. Ultimately, we are attempting to determine whether or not quiet submarines can be tracked with sufficient accuracy. Such a capability could have significant cost implications for the conduct of peacetime surveillance.

The availability of target information could greatly reduce the numbers of ASW aircraft flights and sensors required to conduct routine follow-up operations against patrolling SSBNs. Our objective is to determine the feasibility of reducing the uncertainty area allowing almost sure follow detection by a single aircraft with commensurate savings in flight costs (including fuel), sonobuoys, and maintenance. Naturally, such a capability also has vast implications for the problem of resource allocation in the surveillance system itself.

To meet this objective and to demonstrate significant capabilities in a relatively short time-frame requires that signal processing researchers have access to operational target data. Previously, just getting such data was a cumbersome process, often involving the installation of research equipment in operational stations, which can be disruptive of normal operations. The researcher was then required to return to his laboratory to conduct time-consuming and expensive data reduction and analysis tasks. More often than not, several years passed before his results could be incorporated into an engineering development or production program.

In order to solve this problem, DARPA has developed an Acoustic Research Center (ARC) which is located at

Moffett Field, California. The ARC incorporates the latest data communications and digital signal processing technology in a central facility for the conduct of research and experimentation in ASW signal processing. The ARC has real-time access via satellite communication links to data from several arrays. This access does not interfere with routine operations. The ARC has a massive resident real-time computational capability for data processing and analysis and is connected through a secure link to the ILLIAC IV, the world's largest computer. A recent DARPA development now allows end-to-end operation over the ARPANET, making possible widely geographically distributed processing of data. I will highlight in a later section a major experiment we conducted at the ARC during FY 19TQ which explored an exciting concept and demonstrated the full operational capability of the ARC.

In FY 1977, we are adding a station to the ARC network to provide significantly improved capabilities to cover operational areas. We are also making improvements to the ARC software system which will reduce the cost and enhance the ease and frequency with which experiments can be implemented and executed. In FY 1979, these improvements will be completed and we will begin to transition the responsibility for ARC to the Navy, with the goal of complete transition by FY 1981. In FY 1978, a major experiment is planned to evaluate the effectiveness of sensors. In addition, in FY 1978, the ARC will obtain secure access to arrays.

Another new effort in FY 1978 in the area of passive acoustic surveillance will be a distributed system with a design-to-cost goal of $50 per multiplexed acoustic channel. Our tradeoff study indicates that, although the unit cost of such a system would be higher than the unit cost of existing sonobuoys, the total cost of aircraft detection would be reduced because of the improved detection capability. In FY 1978, the testbed system will be designed and built.

In a related new effort beginning in FY 1978, we will apply state-of-the-art microprocessor technology to evaluate the technical feasibility and operational usefulness of technology which permits, at slightly greater unit cost, the incorporation of analysis functions on small electric chips. Moreover, these data compression techniques allow the RF transmission bandwidth required for data relay to be reduced, thereby reducing the RF power requirement for data relay and significantly extending the useful life of the device. Thus, a rapidly deployable, moderate life system would be available either to augment existing systems or to provide ASW surveillance where such systems did not already exist.

c. <u>Active Acoustic Surveillance</u>. To complement our research in passive acoustic surveillance, we will include in the SEAGUARD program in FY 1978 a new effort in active acoustic surveillance. Active surveillance has not received major emphasis

in prior years. These drawbacks were correctly perceived to outweigh the potential payoff. In recent years, however, relatively inexpensive sources have become available which are adequate to support research and experimentation in this area, if not operational system development.

The ambient noise levels in the ocean are steadily increasing passive surveillance systems due to increased surface shipping and continental shelf development activities. In aggregate, these factors may cause our passive surveillance systems to become much less effective, even if they are capable of performing to the limits allowed by the medium. To hedge against this possibility, it is crucial to understand the potential of active surveillance techniques and to have available for rapid exploitation the technology required to conduct active surveillance if it becomes necessary. DARPA will proceed as far as possible to determine the feasibility of a medium range active acoustic surveillance capability without an expensive acoustic source development early in the program. The FY 1978 program will emphasize critical measurements, development of an inexpensive source to conduct early detection experiments, and target strength measurements. The program will take advantage of receiver and signal processor technology developed in other DARPA or Navy programs to minimize costs.

DARPA has developed a sonar which is specifically designed to detect noise generated by turbulent flow. This noise

emission is unavoidable. At-séa evaluations will begin in FY 1977 and continue to FY 1979. We are also planning to use this array with separate acoustic sources to evaluate the effectiveness of large aperture receivers in active sonar applications.

d. Non-Acoustic ASW. In addition to noise radiated by submerged submarines, there are a myriad of other disturbances to the natural environment attributable to submarines that can provide an alternative basis for submarine detection. In this category are signatures which are primarily electromagnetic, hydrodynamic, or material in orgin.

DARPA's research program in non-acoustic ASW, which complements and is coordinated with Navy programs, emphasizes (1) the development of experimental sensors which, if successful, could lead to significant new submarine detection capabilities and (2) the development of a fundamental and definitive information base upon which advanced detection concepts can be evaluated. The information base needed to evaluate concepts will be developed by a coordinated theoretical laboratory and at-sea experiment program.

5. Land Combat

While much of the overall technology base being developed by DARPA has applicability to the generic land battle, the efforts addressed in this major thrust area are focused on specific problems critical to success in land combat. In addition to ongoing efforts on armor, hostile weapons, and mini-RPVs, new initiatives in tunnel detection, fire-and-forget missiles, and netted radar have been undertaken during FY 1977 and will be continued in FY 1978 to counter new threats posed by increasing capabilities and observed new tactics of potential adversaries' ground forces. The DARPA efforts are characterized by high-risk, long-term, revolutionary approaches as contrasted with the Services' lower-risk, near-term, evolutionary approaches. In all cases, there is close coupling between DARPA initiatives and the Services to assure continued and realistic assessment of returns from R&D investments. We have executed formal program memoranda with the Services which, in some instances, involve joint funding, but, in all cases, will lead to realistic final examinations of the R&D results achieved.

a. Armored Combat Vehicle Technology. If the Warsaw Pact armor threat continues to grow at the current rate, the number imbalance could be overwhelming in the 1980's and 1990's. Is it possible to build an "anti-tank machine gun" mounted on a small, lightweight, highly mobile combat vehicle? Will the cost be low enough to afford twice as many as the current M-60 tank to be used

in a high-low mix with XM-1? We are exploring and developing advanced component technology to provide quantitative answers to these questions.

One of the important factors that determines the size of a tank is the size, weight, and trunnion reaction of the main gun. The current standard M-60 tank mounts on a 105mm cannon. The resulting trunnion reaction is over 100,000 pounds. The rate of fire is determined by the manual reload time. DARPA, in conjunction with the Army, is developing a revolutionary medium caliber (nominally 75mm) automatic cannon which can fire at a rate of up to two shots per second with a trunnion reaction of less than 20,000 pounds (average of 5,000 pounds when firing in the full automatic fire-out-of-battery, soft recoil mode). Such an anti-tank "machine gun" can be mounted on much smaller combat vehicles having greater tactical as well as strategic mobility.

We undertook two options for the automatic cannon--one more conventional approach based on solid propellants, and one more advanced, higher-risk approach using liquid propellants. The latter concept has the advantages of potentially higher muzzle velocity, lower barrel operating temperature, longer life, and higher packing density for the ammunition. After two years of concerted effort to apply existing knowledge, it is clear that a practical liquid propellant anti-tank gun cannot be achieved because of unresolved difficulties in proper ignitions of the turbulent dynamically injected propellant. The resultant delayed

ignition ("fizz burn") has caused unpredictable and uncontrollable explosions in test fixtures. We believe, therefore, it is appropriate to terminate these experiments and revert to a longer-term technology base program to provide an essential foundation of combustion processes and chemical kinetics encountered during multi-shot modes. Accordingly, DARPA will conduct minimum essential experiments and analyses to explain the ignition problem and will prepare a report of the 75mm LP gun activities over the past several years and transfer this information to the Army's Ballistics Research Laboratories.

The solid propellant 75mm gun has progressed satisfactorily. High explosive (HE) and multi-flechette ammunition alternatives have been designed and are being evaluated against attacking aircraft and helicopter gunships. The solid propellant gun is being integrated into the HIMAG vehicle turret for system tests by the Army in 1978.

Automatic cannons may require an advanced fire control concept using the thermal imaging for accuracy and fire-on-the-move capability. We are exploring both closed-loop and open-loop concepts to determine the optimum low-cost approach consistent with the cannon performance characteristics. In order to determine the feasibility and role for this advanced gun technology, we are building a tracked high mobility/agility (HIMAG) test vehicle which will enable us to do experiments with advanced guns and fire control concepts. In addition, the testbed

vehicle is being designed to permit another set of experiments to quantitatively determine the combat advantages of high mobility and agility. The testbed engine, weight, and suspension parameters are adjustable and can be varied systematically to simulate possible future vehicles of various mobility and agility characteristics. The gun, fire control, and mobility/agility experiments have technical feasibility objectives as well as objectives to acquire quantitative data on parameter effectiveness under field conditions. These experiments will be conducted in partnership with the Army.

DARPA is also collaborating with the Army and the Marine Corps in the development of a lightweight (15-21 ton) high survivability test vehicle which will also mount the 75mm cannon.

The overall DARPA program in advanced guns and associated armored vehicle systems was undertaken in response to requests from the Army to apply DARPA technology in revolutionary high-risk alternatives as opposed to ongoing, more evolutionary Army programs. The latter, of necessity, were dedicated to upgrade the existing armored vehicle fleet and develop an urgently needed new MAW BATTLE tank (XM-1). Resources were not available to pursue both courses simultaneously.

DARPA accepted this challenge and formulated and undertook the program on which I'm reporting. We believe the results to date have been very useful. We have surfaced a new and very promising solid propellant gun and ammunition concept.

We have underway the development of testbeds to examine gun and vehicle system alternatives and, most importantly, we have developed means to quantify the tactical utility of those alternatives. The program has progressed to the point where we believe, and the Army agrees, that it can and should be wholly transitioned to the Army by the end of FY 1979. We have executed a formal memorandum of understanding with the Army to effect this transition in that time frame. Our budget request for FY 1978 and our plans for FY 1979 reflect the above described transition of this program.

b. Hostile Weapons Location (HOWLS). By assignment from the DDR&E, DARPA, in a joint program with the Army, is undertaking "R&D in the location of hostile indirect fire weapons normally found within about 30 kms of the forward edge of the battle area (FEBA) in a European environment." Historically, emphasis has been placed on acoustical and optical (flash) detection, but the systems which were developed require manual data processing and were severely limited in both accuracy and response time. The Services have evolutionary programs to improve performance to meet near-term needs, and are also looking at projectile-tracking radars and other (e.g., seismic) sensors. However, new technological development such as improved worldwide navigation systems, remote expandable sensor platforms and, most important of all, the revolutionary development in computer capability, made it apparent that radically new, relatively high-risk, programs could be

undertaken to dramatically improve the sensitivity and accuracy of hostile weapons locations. A series of studies, conducted with the participation of the Army and Marine Corps, defined the problem and identified several promising approaches. Of these, three were selected for major emphasis and some others for further evaluation.

The first will be a small, lightweight, high performance radar, designed to be carried on a mini-RPV and to penetrate to the enemy side of the FEBA. An experimental version of this radar is now being flown in a manned aircraft to gather data on target and background signatures. The most advanced radar technology has been used to provide the stability and flexibility needed for such an experimental program, and a radically new electronically-steered antenna has been developed to enhance its performance. The data from these test flights is being used to develop the processing algorithms for finding enemy weapons against typical clutter backgrounds. In addition, this experimental radar will be used in joint programs with the Army to gather comparative data on millimeter wave radar performance and also to determine whether such a radar could be used to detect moving ground targets, such as tanks, from an RPV.

The second key development in this program is a mortar locating system combining several of the desirable properties of an infrared system and a laser ranging device. The infrared system stares just above the horizon and if the detection of an object which could be a mortar projectile is made, the laser is activated to confirm the target and produce accurate range data. With two or

three such points on the up-leg trajectory, a computer can extrapolate the trajectory of the shell and locate the mortar. Field tests of the first experimental model have been conducted at Camp Edwards, Massachusetts, and China Lake, California. Despite some problems with the detector array, reliable detections have been consistently made. The feasibility of the concept has now been demonstrated, and work will continue to develop a better detector array. With these improvements, it is expected that useful detection ranges against both mortar and artillery shells will be achieved in all but the worst of European weather.

Once an enemy weapon has been located, the next step is to fire at it with a weapon having a high probability of first-round single-shot kill. To this end, our third major effort is in projectile guidance. An artillery tube heats up after firing a few rounds, and we sought to develop a seeker which would discriminate warm objects from the cooler background, and would also reject hot objects (such as fires or flares). We chose an IR seeker and processing logic which first performs spatial discrimination to select candidate targets of about the right size and then used two-color spectral discrimination to select the one whose temperature is nearest to that expected of a gun barrel. An extensive series of tests conducted against simulated targets and real clutter have shown good detection probability against a gun which has fired six to eight rounds.

Further tests will be conducted this year against real targets against a variety of backgrounds and in various weather conditions.

As a result of our work so far, several new techniques for locating hostile weapons have been tested, and in each case feasibility has been demonstrated. Testing will continue in FY 1978 to refine the concepts and to further develop the data processing algorithms. Based on the results of these tests, we believe specifications for operational systems can be generated.

During the program, other new technological developments will be investigated as they appear. Two are under consideration now. In a separate program, DARPA is developing a miniature emitter location system which will also be designed to fly in a mini-RPV. Since the operational characteristics of this system and the RPV radar are complementary, a program will be initiated to combine the two into a single system to locate, identify, and track enemy targets. A related program will investigate the feasibility and the operational implications of combining information from airborne radars, ground radars, and other ground sensors such as UGS or FAALS to provide increased coverage, better accuracy, and improve ECM protection.

c. <u>Mini-RPV Systems and Technology</u>. The miniature remotely piloted vehicle (Mini-RPV) program was undertaken in [illegible] to evolve new Service options for low-cost, low-speed, small, unmanned aircraft for missions such as reconnaissance, target acquisition, target laser designation, and target strike. During

the past year the trend toward more Service development of the previously demonstrated DARPA systems has continued. The early near-FEBA reconnaissance and target designation demonstrations by DARPA have evolved into the Army AQUILA program which is maturing into a successful field demonstration system. Similarly, the Air Force and Federal Republic of Germany are jointly entering a full-scale development phase of the Harassment Drone which is an air defense saturation and destruction system concept pioneered by DARPA under the name of AXILLARY. Finally, the Navy is beginning a development program for an RPV to accomplish target acquisition for the Harpoon missile and the Navy guided projectile. The RPV will be deployable from non-aviation ships and builds on the previous DARPA STAR program as well as previous DARPA sensor and communication efforts.

The efforts remaining for DARPA are the completion of the "loiter mine" seekers and an anti-jam command and control system. The loiter mine concept includes a loiterable aircraft such as the harassment drone with anti-armor seekers replacing the home-on-emitter type. The seekers are currently in captive test to determine automatic target acquisition and false target rejection capability. It is expected that the concept will transfer to the Air Force by the end of FY 1978 after successful seeker demonstration.

The final DARPA investment in the mini-RPV technology area is that of anti-jam communications. Since the RPV would,

for many of these missions, fly directly over enemy territory, it would be expected to see a very high level of both interference and jamming. DARPA, therefore, started a program to develop anti-jam data links which would permit continued operation under all but the most severe jamming scenarios and which would be small, light, and cheap enough to be used in the RPV. The required AJ margin was achieved. This unique approach has met or exceeded all its design goals and will result in a complete RPV communications package which weighs less than 15 pounds and will cost about $7,000 in production quantities. As part of the RPV data link program, it was necessary to pay special attention to the video data link. Standard TV signals have such wide bandwidth (25 Mbps or more) that the direct application of spread-spectrum modulation is virtually impossible. Instead, DARPA initiated a program to reduce the bandwidth of the TV signal by removing both the spatial and temporal redundancy.

Accomplishments in FY 1977, besides the loiter mine seeker and ICNS tests, have included the conclusion of the AEQUARE flight tests and the STAR automatic recovery system tests. The AEQUARE RPV can be carried and launched from a fighter aircraft. We have proved the AEQUARE launch concept in four successful flights. However, the ability to attain high launch sequence reliability in a simple system, affordable as an expendable unit, is uncertain and further assessment is necessary. The STAR vehicle was launched and recovered in a fully automatic pre-programmed mode (i.e., no manual control required). These tests demonstrated a

concept of mini-RPV operation from the pitching deck of a ship. Additional tests will be undertaken at sea and the results factored into the Navy RPV program.

In summary, after developing mini-RPV concepts and supporting technologies for five years, we are successfully completing and transitioning these efforts to the Services. In this time, new low-cost options for some critical airborne missions have been demonstrated by DARPA and accepted by the Services for specific mission evaluation. The survivability of such RPVs against air defense has been evaluated both analytically and in tests against real weapons so that Service system mission designs can be confidently pursued. Supporting payloads for laser designation, day or night surveillance and target acquisition, emitter location, and anti-jam command and control have been successfully developed. The DARPA program will end after the final ICNS and loiter mine developments in FY 1978.

d. Fire-and-Forget Missile Guidance. Drawing on the basic technology of high density infrared focal planes being developed under the DARPA space surveillance activity, we have initiated research leading to a family of low-cost, day-night, fire-and-forget seeker approaches. The fire-and-forget feature precludes current practices of maintaining aimpoint on a target while a missile or warhead is inflight to target, and thus greatly reduces the gunner's exposure to counterfire. Working with the Army Missile Command and the Night Vision Laboratory,

we have completed a design evaluation and simulation activity which has resulted in favorable performance estimates. Cost reduction of factors of three or even greater are also projected. We believe that these approaches will make possible both seekers for single man-portable missiles as well as air-launched systems. Our present activity will exploit the results of this design and performance evaluation by fabricating brassboards for captive flight test. On completion of this effort, we believe that the technology base will be established for a new generation of high performance, low-cost, launch-and-leave missile seekers for a wide variety of tactical applications.

e. Netted Radar Program. The Army and Marine Corps currently use ground surveillance radars for detection of moving targets such as vehicles or personnel and for limited classification and localization. Although valuable as surveillance devices, they tend to be severely limited by terrain masking and by background clutter. The line-of-sight limitation can be eased by using airborne radars but these, in turn, are expensive, vulnerable, and cannot fly in all weather.

Recent technological advances, particularly in computer processing, have made it possible to realize significant improvements in the performance of ground surveillance radars. A joint DARPA/Army program has been initiated in FY 1977 with the following goals:

(1) Addition of sophisticated detection circuitry to remove background clutter and permit detection of moving targets out to the maximum line-of-sight (LOS) range.

(2) Provision of sufficient processing and storage in each radar so that its output data (target tracks) can be passed over narrowband telephone lines.

(3) Interconnection (netting) of a large number of radars to increase area coverage, and to alleviate the line-of-sight problem.

(4) Interconnection of this netted ground-based system with airborne radars such as the Army SOTAS.

(5) Interconnection with display facilities such as the division Tactical Operations Center (TOC), and fire control systems such as TACC or TACFIRE.

Preliminary studies have indicated that a distributed netted radar system will not only provide increased ECCM capability due to both the MTI processing and the variety of look angles provided for each target, but also will provide a defense against anti-radiation missiles by permitting "blinking mode" operation.

The DARPA program will start by modifying two or more existing radars and demonstrating netted operation with SOTAS. Based on the results of tests conducted with this system, a new ground surveillance radar and radar integration center will be designed, built, and tested.

6. Command, Control and Communications (C^3)

DARPA research in this multi-discipline area encompasses a broad spectrum of research and exploratory development efforts ranging from the storage, retrieval, processing, and distribution of vast amounts of data, reports, and commands among widely distributed locales, to means of enhancing performance of commanders and operators employing C^3 systems. Efforts are focused on advanced technologies in computer communications, secure message and information systems, crisis management, human factors in C^3, and on an advanced C^3 testbed.

a. Communications. In addition to secure voice, large area military command and control must depend on computer-based information systems. Reliable and responsive computer-communications techniques are required which can connect the command structure and supporting operational, intelligence, logistics, and environmental data bases distributed around the world. To interconnect these elements in a useful manner, over both long distances and in possibly remote crisis areas, a dynamically allocated, multi-destination, worldwide computer-communications capability is required. DARPA is conducting exploratory development in two relevant computer-communications technologies, packet broadcasting via satellite, and ground radio. Packet transmission techniques consist of sending, via wire or radio, sequences of one or more groups of data in digitized form, where each group or packet contains the address of the intended

recipient, the data, and some error control digits. When a packet is received by any network switch, its address is examined to determine the destination and then it is forwarded or used locally as determined by the address. The digital nature of a packet communication system easily allows the provision of standard data encryption for security. A significant advantage of a packet broadcasting system is that messages to many different users can be sent over the same wire or broadcast on the same frequency. Packet broadcasting by satellite will permit two or more earth stations to share a common communications satellite channel. This technique could replace the present point-to-point satellite circuits now available with a multi-destination, multi-access system which can be expanded quickly in time of emergency to new crisis locations and permit the priority allocation of capacity to emergency traffic. An experimental, two earth station packet satellite link between the United States and England was opened in September 1975. Initial systems tests have been conducted and experimental computer-communications over the link with three earth stations will begin mid-FY 1977. The third station, in Norway, will permit multi-station operation of the system and voice conferencing experiments to be conducted. A small unattended earth station at COMSAT Laboratories will be added in FY 1977 for testing with a mix of earth terminals.

Packet broadcasting by ground radio is a radically new DARPA effort which is developing techniques and equipment to

handle packet-switched computer-communications among fixed and mobile tactical terminals. Experiments have been completed which show great potential for providing: (1) 100-400 kilobit/second data links to tactical data-systems users; (2) major improvements in efficient utilization of the radio frequency spectrum for users with low duty cycle "burst" traffic by sharing the use of a common wide-band channel; and (3) direct computer internetting with other packet-switched networks such as AUTODIN II. The initial packet radio repeaters, central station, and system software have been developed and an initial small-scale network test was conducted late in FY 1976. Tests of a larger packet radio network are planned for FY 1977 and FY 1978 and tests in an Army tactical data distribution environment are planned to begin in late FY 1978. Both secure data and secure voice could be transmitted over packet broadcasting systems. Using packet-switching techniques to route data, various elements of a command could exchange information; access operational, intelligence, and logistics data bases; and connect to other data bases or headquarters through a connecting packet satellite or packet radio network link.

A long-range goal of the Defense Communications System is to integrate digital and voice communications into future Defense communications networks. The basis for data communications in a packet-switched network has been verified by the success of the ARPANET and will be implemented in AUTODIN II.

During late FY 1977 we expect to demonstrate the combined operation of the satellite network, the ground radio network, and the ARPANET. This will provide a basic internetting capability which can also be applied to AUTODIN II. A promising DARPA effort is concentrating on the goal of developing the capability for transmitting secure compressed digital speech over a packet-switched computer-communications network. Successful transcontinental speech communications have been demonstrated at average data rates of one to two kilobits/second with high quality over the ARPANET. This capability will also be demonstrated on the satellite and ground radio networks during FY 1977 and FY 1978. Such a capability is expected to provide a secure voice conferencing capability that could be used with the future AUTODIN II Phase II network and provide a basis for computer-based voice message systems.

b. Advanced Command-Control Architectural Testbed (ACCAT). We previously described a testbed in which new technology emerging from the DARPA Information Processing research program would be applied to command-control applications and evaluated in an operational context. The first increment of this testbed, which is termed the Advanced Command-Control Architectural Testbed, or ACCAT, is now operating. This increment is located at the Naval Electronics Laboratory Center (NELC) in San Diego. ACCAT's development has been a joint effort with the Naval Electronic Systems Command (NAVELEX). The Navy's Command-Control Architect (OP-943C) has also informally participated in the role of a consultant outlining capabilities which ACCAT should provide.

The ACCAT facility at NELC consists of an Applications Laboratory located in the new Electronics Development and Test Laboratory on Point Loma. The Applications Laboratory is an Experimental Command Center which can be used to represent Navy command centers afloat or ashore. The command centers, if two are represented, can be independently supported by interactive time-sharing computers which are also located in the Applications Laboratory. These computers are securely interconnected via the ARPANET which represents the future DoD AUTODIN II network. It is now possible, using the ACCAT as it has been developed over the past year, to simulate the flow of command information between two widely separated naval command centers and to support the decision-making processes in each.

Through the use of secure ARPANET connections, ACCAT can provide connectivity to remote sites throughout the continental United States as well as Hawaii and portions of Europe. ACCAT can thus become a geographically distributed testbed with real-time access to sites at key sources of information and to sites where decision makers employ this information for command and control of their forces. During the coming year, we plan to extend ACCAT to a limited number of selected command and control RDT&E sites.

ACCAT is not being developed as an operational command and control system. Rather, it is a flexible design tool for command and control which is matched to the problem and which

provides an adequate operational context for credibility. ACCAT users are distributed geographically because the command and control problem is a distributed problem with significant differences in needs at the different sites. ACCAT is optimized for ease in functionally simulating the capabilities of future command and control systems. The technology, both hardware and software, employed in the ACCAT is representative of the technology which we believe will be employed in the operational command and control systems of the 1985 to 1995 period. ACCAT is thus not only a vehicle for determining the architecture and functions for systems of this period, but also for evaluating the technology upon which future systems will be built before making a hard and possibly costly decision to employ it.

c. Secure Message and Information Systems. This research has two related objectives: achieving computer system and network security, and introducing interactive computer techniques to the military message system. The latter will rely on the development of capabilities to achieve computer-communication network security (which goes beyond conventional encryption of communications links and is focused on end-to-end encryption techniques for packet networks) as well as authentication techniques. A point-to-point packet-switched network encryption device, certified in 1975, is now in use transmitting ASW data on the ARPANET in connection with the DARPA Acoustic Research Center (ARC). Work in 1976 focused on end-to-end encryption systems suitable for

multi-destination use and initial application will be early in 1977. The second aspect of this research addresses the security/integrity of levels of classified information inside military computer systems and techniques which control and authenticate access to these classified operating systems over a computer-communications network. Techniques to detect security flaws in computer operating system software, completed in FY 1976, are now in use by the Services and Defense Agencies.

A verifiably secure minicomputer operating system monitor was demonstrated in FY 1976 as a forerunner of a secure general purpose minicomputer operating system to be completed in FY 1977. A three-year effort to implement a certifiably secure version of a major vendor's operating system began in FY 1976. Research on the design of interactive secure systems with a high degree of user acceptability began in FY 1976, and will lead to secure message handling system in FY 1978.

Deployment of the experimental message system to CINCPAC Headquarters, as part of the DARPA/Navy military message experiment, will take place in mid-FY 1977. The purpose of this two-year experiment is to evaluate the characteristics of an interactive military message system suitable for use in an operational DoD environment. Such systems are critically needed to support the crisis operations in large military headquarters. During such operations, major increases in message traffic occur and timely action is required to respond to these messages and to initiate messages directing military actions. The military-oriented

message system has been completed and final preparations for the conduct of the experiment are underway. The results of this effort will guide the development of secure interactive message systems for general DoD use.

d. Crisis Management. The goal of the Crisis Management program is to develop or apply advanced technology for forecasting the occurrence, intensity, participation, impact, and outcomes of crises sufficiently far in advance to significantly facilitate national defense. The current defense warning and management process has not changed in many respects in at least 25 years. This state of affairs has in a number of instances (e.g., the Czechoslovakian invasion by the Soviet Union in 1968, the Middle East War of 1973, and the Pueblo crisis) resulted in the US National Command Authority having neither appropriate warning of impending crises nor their being able to generate a timely response. A significant part of the reason for this continuing problem is our lack of progress in developing and applying new technology in this critical area. For example, in an era of declining manpower resources, information is still processed manually; all phases of the process are carried out by individuals reading, sorting, assembling, discarding, and digesting information and data. The result is that little time is available for analysts and decision makers to perform the most critical tasks of all--the analysis and interpretation of the information and data gathered at such great expense. Further, despite wide recognition that political and economic factors are of critical and

increasing importance to the national security warning and management process, we nevertheless persist in relying almost exclusively on military indications and warnings.

Specific emphases within this program are designed to improve our warning and management capabilities by exploiting recent advances in basic crisis forecasting and decision-making research in the social, behavioral, and computer sciences. Our unique approach includes the use of computers for storing, retrieving, sorting, and displaying information and data; techniques for the integration of military, political, and economic data and indicators; and the use of new analytic tools such as event analysis, computer content analyses, and hierarchical inference. Further, relatively inexpensive, but powerful, stand-alone mini-computers provide the required computer basis.

Work to date has focused upon the test and evaluation of a computer-based user-oriented warning system incorporating diverse indicators, the development of executive aids for improved crisis management in problem areas such as option generation and selection, and the solution of problems associated with special cases of crisis such as terrorism.

The development of a first stage crisis early warning system, comprised of quantitative international political indicators, a short range forecasting capability, and the required interactive computer software, has been completed. Preliminary testing of the crisis early warning prototype system is completed, using retrospective forecasting techniques on past crises.

Several case studies of terrorist incidents, derivation of a basic data set of past terrorist activities, and preliminary work on deriving decision roles for the development of terrorist models also has been finished.

Currently, a second stage crisis early warning prototype system is being developed and tested with enhancements, including the use of natural language processing techniques, to automatically encode message traffic as a unique approach to the data input problem; the use of pattern recognition methods to upgrade system capability to identify and "lock on" to behavior patterns; the expansion of capabilities of the system to include foreign internal indicators in addition to the more common international indicators; and the addition of options to screen potential crises for level of US national interest and commitment. A crisis management executive aid aimed at applying linear programming techniques to option selection and evaluation during the crises is being developed and new approaches and methods for the development of computer-based models for estimating the impact of US "signaling" on military decisions of foreign powers during crises is being explored. A preliminary planning effort is also underway to identify the most promising techniques for forecasting and managing terrorist-related crises.

In future fiscal years, full natural language coding from unformatted test should be achieved; all-source computerized data bases will be integrated into the early warning system; and

it will be possible to integrate military indicators into the evaluation of potential crises with respect to international and foreign internal indicators, as well as economic indicators. Off-line parallel testing and evaluation of the early warning system will also take place with an operational defense agency. Models of the decision processes and perceptions of other nations will be completed. Additional computer-based executive aids for high level decision-maker use during crises will be completed, including aids to information requesting and selection, and prediction of likely responses to alternative policy options. Conceptual design and preliminary development of a computer-based system to aid in forecasting and managing terrorist incidents will be completed.

The results of this research effort are expected to have major impacts on defense crisis warning and management capabilities. These include faster information processing, sorting and distribution which will be improved by a factor of five to ten, more efficient and comprehensive option generation and evaluation, and more accurate and timely warning of impending crises. These new capabilities will increase our ability to not only more effectively deploy forces for improved crisis management, but will enable US decision makers to avert crises which directly or indirectly threaten US national interests.

e. Packet Satellite Experiment. Present commercial and military communications satellite systems provide only point-to-point

service with some limited one-way multi-receiver capability. Generally, connecting users at each pair of earth stations requires a separate circuit which can not be shared with other stations. These systems do not make the most efficient use of satellite communication resources.

The DARPA approach is focused on mini-computer controlled techniques which permit the dynamic sharing of a communications satellite channel by a number of distributed earth stations at data rates required for effective error-free, computer-communications based command and control systems. The technology used in this work is an adaptation of the packet switching techniques demonstrated over the past few years in the ARPANET. Capabilities have been added to permit earth stations to contend for satellite resources under varying system loads, to allocate satellite resources to priority users, and to add or delete earth stations gracefully.

In September 1975, a 50 kilobit per second satellite link was opened between the US and the UK over INTELSAT IV. Since that time the satellite interface message processors and necessary interfaces required to permit packet satellite operation have been checked out and placed in operation, a number of experiments exploring the utility of various contention modes have been conducted, and measurements of the parameters effecting system operation and through-put instituted. A priority oriented demand assignment (PODA) technique has been developed which

optimizes the allocation of the satellite communications channel among a number of earth stations, transmitting both data and speech, and supporting users with differing priorities. Implementation testing of this technique is beginning.

Successful implementation of this capability in military satellite communications system will be particularly important in supporting computer-communications traffic, which is expected to become an ever-growing component of military command and control systems. This capability can be allocated on a dynamic basis to a crisis or high priority area and 10 to 100 times more users can be accommodated through this communication resource sharing technique. Note that this capability is achieved without the need for new satellites or earth stations. This technology is expected to provide the basis for the satellite portion of AUTODIN II, Phase II, in the 1985 time-frame.

During the coming year, an additional earth station will be added in Norway and a small earth station will be added at COMSAT Laboratories in the US. The four earth stations involved, plus the mix of large and small earth stations, will permit the full capability of the technology to be demonstrated and measured. Planning will continue with the Defense Communications Agency for a military test of this technology on a military satellite system.

f. Command Systems Cybernetics. The impact of new command system cybernetics is another important aspect of the DARPA research in C^3. The central function of command, control, and communications

is to manage military resources. The management process involved in formulating and communicating commands is usually influenced by a massive flow of information, the consequences of prior commands, projections of the consequences of various courses of action, and the personal and organizational values of commanders. For the foreseeable future, people, rather than computers, will be making command decisions. Human limitations in formulating and communicating commands will be a central difficulty in increasingly complex command, control, and communications systems. In anticipating this problem, DARPA has initiated research aimed at developing and demonstrating a new type of command systems cybernetics, principally concerned with the development of a new technology for information management. Capabilities will include spatial information storage and retrieval, in contrast to the symbolic information storage and retrieval capabilities usually included in command systems; new techniques for adaptive information purchasing to allow information selection at high speed, with consistency during crises under stress, with large amounts of information and with a high signal-to-noise ratio; advanced techniques for information pacing, reducing the problem of information overload and eliminating difficulties of lost vigilance resulting from information overload; new approaches to information structuring, e.g., the reordering of information to improve comprehension and memory; and ultra-rapid picture/prose presentational means to dramatically increase information bandwidth while improving comprehension and memory. Complementing capabilities

for advanced information management are technologies for aiding reasoning and problem solving, as well as heuristic modeling. These will allow the commander to quickly create plausible alternatives for action during times of crises when problems of optimum resource allocation will tax human abilities to make effective decisions. Finally, we are facing the special problem of group decision making, group problem solving, and group reasoning. Solution of these problems requires automated aids to assist heterogeneous groups in understanding communications, combining resources, and reaching decision concensus in an optimal fashion.

7. Lowering the Cost of National Defense Through Technology

A sampling of our efforts in this important area includes:

a. Ceramic Turbine. Metal gas turbines, in addition to their widespread use in jet aircraft, have almost pre-empted the field of helicopter power plants and are now undergoing major introduction into naval fleets such as the DD963. In the field of ground transport, however, the use of these turbines has not yet made a significant impact. Although they have been experimentally demonstrated in trucks and automobiles, neither the first cost nor the operating cost (fuel consumption principally) has been within reasonable bounds. The difficulties in improving efficiency in relatively small turbine engines required for automotive and missile uses are formidable and require that bold steps be taken if significant advances are to be made. The DARPA program on brittle materials design/ceramic turbines is such a step forward and promises to achieve this through a significant increase in turbine inlet temperature.

The DARPA program has the broad objective of demonstrating operation of engines, all of whose hot parts are comprised of ceramics, at a turbine inlet temperature of 2500°F. In FY 1977, the program involves three separate but related efforts: one to investigate how to attach ceramic rotor blades to a superalloy turbine disk; a second to achieve automotive size engine operation for 200 hours with temperature cycling

up to 2500^{o}F, using low-cost materials fabrication techniques; and a third effort to demonstrate the significant engine performance improvements which are obtained upon using ceramics. The vehicle selected for this demonstration is a US Navy PCF "Swift" class boat. It presently utilizes two diesel engines. In the DARPA program, one of the engines will be replaced by a conventional metal gas turbine and the other for comparative purposes will be replaced with an experimental turbine wherein all high temperature parts will be ceramic.

Progress in the first two phases of this program includes the successful testing of the large vanes at 2500^{o}F and the testing of the ceramic-bladed superalloy rotor for 25 hours at 2250^{o}F with a speed of 35,000 rpm. For the small automotive turbine, all stationary parts have now passed the 200 hour DARPA duty cycle up to 2500^{o}F and a ceramic rotor has been tested to 80% of design speed at 1930^{o}F.

The estimated thermal efficiency for an open, non-regenerative gas turbine without cooling bleed air extraction is estimated to be 41% at a turbine inlet of 2500^{o}F (the objective of the DARPA program). The potential improvement in efficiency and in fuel consumption, attributable to use of a ceramic turbine at 2500^{o}F, is about 17%. Other advantages include resistance to abrasive dust and corrosive sea salt spray which reduce maintenance and increase life-cycle costs. In addition to potential performance gains, ceramics are made from raw materials which are inexpensive and available and avoid the serious problems of material availability implied by

the use of superalloys, some of whose components are not available domestically. Although good progress has been made and the raw materials are cheap, it is too early to assess the potential cost of ceramic high-performance structural materials since their processing has not yet been completely developed.

b. Materials Design and Life Extension. Many parts in military hardware fail because of wear. The mechanisms responsible for this wear have never been clearly understood. Until recently the theories of wear were not consistent with experimentally-observed results. Consequently, most methods used today for the prevention of wear are totally inadequate. DARPA has responded to these needs by sponsoring research to develop a new theory of wear (the delamination theory) and methods for both detecting and analyzing the nature and source of wear particles in engine oil. The delamination theory of wear has proven to be accurate in predicting the conditions of wear, the characteristics of wear particles, and potential methods for preventing wear. For example, plating low carbon steel with a thin surface coating of soft metal has been shown to reduce the sliding wear rate by a factor of 1000, as predicted by theory. In a complementary effort sponsored by DARPA, a technique called "ferrography," in which both magnetic and non-magnetic ultrafine particles suspended in engine oil are aligned in a strong magnetic field for microscopic analysis, has proven to be extremely valuable in discriminating several

distinct stages of wear during engine life. Ferrography has proven extremely valuable in averting failures of nuclear submarine main bearings and those on the Mark 5 gun mount, in addition to detecting wear particles in engine oil. By combining the predictive capabilities of the delamination theory of wear with the analytical capabilities of ferrography, a focused effort is being made to demonstrate the potential of dramatically reducing wear associated with aircraft components whose inspection and replacement have a high cost impact on system life cycle costs. Successful results in these demonstration efforts would greatly reduce these costs, not only through better wear control, but also by giving major support to a "maintenance-for-cause" policy.

Another project which seeks to apply new technology to reduce costs deals with innovative non-destructive inspection procedures. Our effort is oriented toward direct inspection methods which will decide whether or not a structure can survive its life-cycle mission. Applied to military equipment, these new procedures should produce a real determination of the impact of a materials flaw on the performance of a component. Today, non-destructive inspection is almost exclusively qualitative and depends heavily on the operator. Our approach is to analyze and quantify the acoustic signatures of parts, the ways in which these signatures are changed by different types of flaws, and the fundamental reasons for these changes. To aid in the development and characterization of

instruments and methodology, flaws of known geometry are examined by several methods in laboratory experiments and theoretical analyses. A central thrust of the DARPA effort will be to bring into practical application many of the test techniques which have heretofore existed only in laboratory or early developmental stages, as well as to standardize procedures for better known techniques. The theoretical methods of fracture mechanics will be applied to experimental flaw signature data to interpret these observations in terms of useful life remaining in the tested parts. There is a critical need to develop viable ways of field testing items in service to assure their reliability. On one aircraft type, for example, some 5,000 tapered fasteners will be pulled from critical wing areas on each aircraft to provide a solid statistical base to judge whether or not dangerous cracks are forming under the heads of these fasteners. Such a major labor-intensive effort, which grounds a plane for long periods, could be obviated by quick, convenient and accurate methods based on acoustic or electromagnetic methods and on-line decision-making under consideration in the DARPA program. A new non-contacting, non-destructive inspection technique has already been developed. The non-contacting feature of this approach is unique and promises to further reduce the cost of structural parts.

c. Integrated Circuit Design and Life Extension. The DARPA program in integrated circuit technology comprises two thrust efforts: (1) process measurement and control technology for the manufacture of integrated circuits having "built-in"

rather than expensive and undependable "tested-in" reliability; and, (2) computer-based process and circuit design aids to eliminate long lead time and non-recurring cost barriers to widespread use of custom integrated circuits in DoD systems. Ultimately the results of these two efforts will be combined to assure availability of reliable new and replacement circuits through well-documented circuit and process design techniques, process monitoring tools, and vendor qualification procedures for procurement purposes.

The process measurement effort is conducted jointly with the National Bureau of Standards. One major contribution has been controlling the reliability of bond wire connections for large circuit applications. In one system, operational bond failures were reduced to zero. These improved bonding controls are now being incorporated into commercially-available equipment by several manufacturers. In another task, reliable techniques and standards are being developed for using sophisticated surface chemical analyses for both integrated circuit process monitoring and failure diagnosis. Equipment for such analyses has been coming into widespread use for process control and failure diagnostics by DoD circuit vendors, but without adequate procedural documentation and calibration standards for silicon device applications. During FY 1978, major emphasis will be given to test patterns for integrated-circuit process control and validation and new techniques and standards for the dimensional measurement of integrated circuit photo-mask features.

The effort in computer assisted process and circuit design aids has as its goal elimination of the time-consuming and costly development of mutually compatible design and process specifications for custom integrated circuits. The ability to directly couple circuit design and modeling aids with manufacturing process specifications is essential to achieving this goal. Research through FY 1977 emphasized experimentally based models for predicting the output of the fundamental process steps of oxidation, ion implantation, and epitaxial growth. In FY 1978, emphasis will continue on modeling of these processes, with emphasis on predicting the output (oxide thicknesses, impurity doping profiles, etc.) of sequential process steps representative of circuit fabrication procedures. Also, development effort will be increased on computer numerical and simulation techniques to integrate the process models into the circuit design procedure.

d. Unique Manufacturing Methods. There is a considerable potential for reducing defense procurements costs through improved manufacturing methods. Several innovative programs in this area are being conducted in DARPA. For example, averaged over the production of an aircraft jet engine, the machining cost per pound of finished superalloy parts is approximately $350. This is due to the extreme hardness and strength of superalloys which render conventional machining methods extremely slow and laborious. Various super-hard and effective abrasive materials are available, however; we have never been able to form them into tool bits for machining

purposes. In the DARPA program during the past year, we demonstrated that the use of cubic boron nitride tool bits allow machining speeds to be increased from five to ten times (depending on the particular superalloy). In one particular application, total machining cost for a given part was reduced by a factor of ten. The process has now been released for commercial adoption, and is used daily in production by several aerospace engine manufacturers.

Another way of reducing production cost of metal parts is to avoid machining entirely by using a casting process. Unfortunately, it has never been possible to do this effectively with steel because of the great heat of molten steel which destroys the dies into which parts are cast. The conventional practice of sand casting is a laborious process requiring a new die or mold for each part; and the part thus produced still requires substantial surface machining and clean up. A radically new approach to casting is now under development in the DARPA program. Some materials, such as synthetic paints and inks, and even liquid/solid mixtures of iron and steel, have the interesting property of becoming thinner, more mobile liquids as they are stirred more and more rapidly. By continuous stirring while cooling, steel can be made to physically behave as a liquid at relatively low temperatures and can then be cast into dies without melting them. In this method, die surface temperatures rise only to about 650°F, as compared to some 1800°F if completely molten steel is used. This great reduction in temperature enables

the dies to be reused many time, resulting in the practical feasibility of using accurate steel dies which yield cast parts so precisely formed that little or no subsequent machining is required. Further, since the cooler dies are long-lasting, the whole process is amenable to automation, resulting in low-cost parts. Stainless and high carbon steels, as well as aluminum and copper-base alloys, have been effectively cast in a laboratory version of this process, and final development of this process is now being transferred to the Army. When development is completed, we expect to see major savings in defense procurements as well as the benefits of a superior product due to this development.

Another metal forming program has had a major breakthrough within the past year where research has shown that high-carbon steels can be made super-plastic. This means that, for the first time, these wear-resistant high-strength steels will be formable into complex useful shapes. Many applications should accrue to the Defense Department.

e. Cybernetics of Instructional Systems. The Cybernetics of Instructional Systems Program has as its goal a DoD instructional technology base that will lower the cost of training and provide instructional strategies which could lead to superior training without increasing costs. DoD training costs are estimated in FY 1977 at six billion dollars per year. Fifteen to twenty percent of all DoD personnel are in training

at any point in time, and most training costs are associated with student and instructor pay and allowances (43%). Thus, if we can reduce training time, we will reduce training costs.

DARPA research efforts in this area differ from activities carried out by the Services in several respects. First, our strategy is to focus on the use of advanced technology--mainly computers--as a solution to long-term DoD training problems. Where the Services must be concerned with immediate requirements, DARPA focuses on emerging technologies and their potential applicability to the more general problems of DoD training. Second, our main focus is on searching out unique technical ideas which, if successful, would have a high impact on DoD instructional systems, but are too risky for any individual Service to support on its own. Third, DARPA acts in a catalyst and coordination role by encouraging and participating in the solution of tri-Service problems. Further, the independent OSD-level perspective provided by DARPA in this critical and increasingly expensive defense activity has been and will increasingly be a major factor in the futurein reducing defense training costs through the application of advanced technological concepts.

The technical approach followed in this program is to exploit computer-based training systems in three areas: (1) the development of prototype computer-based instructional delivery systems to reduce costs in the design, management and operation of military instructional systems; (2) authoring research which

focuses on reducing the time and cost to produce high quality computer-based instructional materials; and (3) instructional strategies research which focuses on the reduction in time/cost of training by relating characteristics of individual trainees to instructional content and media.

Our major investment in computer-based instructional delivery systems has been in PLATO IV. This system, developed partially under DARPA support, is now commercially marketed and is the most advanced system of its type. PLATO IV evaluation at Chanute AFB indicated that the system itself is highly reliable (96% uptime); that system response time is well under a second with a peak load of 450 students system-wide; that performance of the PLATO IV group is equal to or superior to a conventionally trained group; that time savings, compared to conventional curricula, is 40%; and that student and instructor attitudes are very positive. These results replicated prior findings. Transfer of PLATO IV technology is proceeding and the Services will pick up the total funding of PLATO terminals.

A major problem was identified in the field test of PLATO IV. This is the observed difficulty in bringing authors who use these systems to the level of competence needed to produce good curriculum materials in a reasonable time at an acceptable cost. This problem is especially acute in DoD because of the high turnover of authoring and instructor personnel. Thus, our major

research thrust for FY 1977 in authoring is designed to reduce by 40% the time to develop validated curriculum materials.

Design studies for a DoD (rather than Service-specific) computer-based instructional delivery system for the 1990's based on evaluation results from several systems, including the Air Force's Advanced Instructional System and the Army's Computerized Training System, will be initiated in FY 1978. The FY 1978 research in authoring will center around evaluation in a DoD context of the cost effectiveness of computer-based authoring systems developed in FY 1977; initial evaluation of computerized procedures for structuring training materials; and development of computer-based delivery systems to teach personnel in training commands to prepare individualized instructional materials for school-based training via computer-based delivery. Finally, during FY 1978, instructional strategies research will be aimed at developing and evaluating procedures for training individuals to work in teams (e.g., cooperative behavior) and developing and evaluating procedures based on individual characteristics (e.g., intelligence and personality) to improve mastery of computerized training materials.

f. Software Technology. DoD is becoming increasingly dependent on computers for mission effectiveness. While industry has been effective in reducing the cost and increasing the performance of computer hardware, DoD has fallen behind in the development of standards, procedures, and software technology to exploit that hardware for national defense. Increasing concern over poor software reliability, inability to respond to changing

requirements, cost and schedule overruns, and other software problems has resulted in a comprehensive DoD-wide program to improve the management of software projects in the near-term and to achieve fundamental technology improvements in the longer term.

Key problems for which technological improvements are needed include inadequate requirements analysis; lack of design flexibility; poor reliability; inability to transfer existing software to improved hardware; inadequate control over expenditures; lack of management visibility during software development; and the fact that new standards, procedures, and tools are needed to deal with innovative hardware technologies such as microprocessors and computer networks.

DARPA chairs the Research and Development Technology Panel which coordinates DoD programs addressing these issues. This panel is chartered jointly as the management steering committee for embedded computer resources and the OSD Automatic Data Processing Policy Committee. DARPA is also sponsoring research in selected software technology areas. Specifically, we are developing configuration management techniques for command and control and other geographically distributed systems; developing rigorous verification techniques which will substantially improve software reliability; developing advanced tools and techniques for engineering real-time microprocessor software and systems; and developing an improved capability for demonstrating and distributing software tools to the developers and maintainers of defense software, both within DoD and at contractor sites.

During the past year, major milestones were achieved in the effort to develop tools for rigorous software verification. This research, which is targeted for a substantial demonstration during FY 1979, will have a major impact on the reliability of future defense systems. Important milestones were also achieved in the effort to develop a software tool repository and distribution system. The basic framework of this "National Software Works" is in place, and is being evaluated by Air Force and Navy personnel. The ability of computer networks to facilitate software distribution, maintenance, and intraproject communication among geographically dispersed contractors is increasingly recognized, and the Services have projects underway to exploit this technology. Thus, a bridge has been established which will greatly facilitate the transfer of innovative software technology into operational use in the future.

g. Vehicle Maintenance. Current estimates of the annual costs for field maintenance (below depot level) of the US Army land vehicle fleet exceed one billion dollars. The annual maintenance costs for some tactical vehicles are a significant fraction of acquisition costs.

DARPA has initiated research studies with the objective of determining the payoff of advanced technology on this critical problem. Results to date show as a first step the need for a comprehensive monitoring system to permit accurate and detailed records of vehicle operation and maintenance under actual field

conditions. Current practices of obtaining such information involve either surveys of field operators and mechanics or the use of bulky test equipment which is limited to measuring only a few parameters before it interferes with vehicle operations. Preliminary design of an advanced system which can inconspicuously and reliably monitor al' of the important parameters relating to vehicle use, condition, and maintenance has been completed. This Vehicle Monitoring System (VMS) will combine microprocessor and advanced transducer technologies to provide a relatively inconspicuous, on-board, real-time record of how a vehicle is used, fails, and is maintained. A detailed design and engineering prototype contract has been initiated with the goal of having VMS units available by early FY 1978. The VMS will be an extremely flexible research instrument for investigations of vehicle operation, failure, and maintenance under field and test conditions.

Research studies also indicate great potential value of vehicle diagnostic systems which can rapidly reach diagnostic decisions about vehicle conditions without interference with vehicle operation. All previous efforts in vehicle diagnostics involve fairly complex installed sensors and separate readout systems to diagnose failures and operating conditions. Advanced Vehi Signature Analysis (VSA) systems which automatically interrogate vehicle electromagnetic, acoustic, thermal, and other observables to provide diagnostic information are now being considered. These systems are

envisaged as non-contact devices utilizing advanced signal processing and machine intelligence techniques to reach diagnostic decisions.

Army commands and agencies have closely cooperated with DARPA in this endeavor. The Army Tank and Automotive Command is actively involved in both the VMS and VSA efforts.

The success of VMS, VSA and other diagnostic system projects offers the possibility of significant impact on vehicle design to reduce failure frequencies and on maintenance action to reduce manpower and repair parts consumption. Selected diagnostic systems properly deployed and used could greatly increase vehicle readiness and the accuracy of vehicle readiness information.

8. *Laying the Groundwork for Future Technological Revolutions*

Relatively short term research and technical assessment of new concepts and phenomena is a continuing and vital DARPA thrust. The following are selected examples of pioneering efforts to break new technological ground.

a. Autonomous Terminal Homing. The purpose of the autonomous terminal homing program is to develop and demonstrate those technologies which are critical to the achievement of self-contained weapon delivery accuracies significantly greater than under development by the Services. During the past year or so, we have investigated a wide range of associated technical issues in order to characterize the critical parameters, determine fundamental constraints, and identify promising technical solutions.

A variety of advanced sensors were found to be potentially suitable for this application. Thus, a program was structured to begin in FY 1977 to address the technologies critical to these objectives. There are three main thrusts: the development and quantified comparison of several fundamentally alternative techniques for scene-matching; the technique for scene-making; and the generation of a target signature data base to provide input data to the other two tasks as a function of advanced sensor characteristics such as resolution, wavelength, field-of-view, active or passive, etc. In FY 1978, a selection of the two or

three most promising scene-matching approaches and two advanced sensors will be made based on these quantified sensitivity studies. Brassboard developments will be initiated so that the next level of technical issues may be evaluated. Reference scene-making will also be refined and further developed.

b. Unconventional Defense Technology. Recognizing the significant impact that the space applications of high energy lasers will have on strategic philosophy, planning, and force options, DARPA, in FY 1976, initiated a program in unconventional defense technology (UDT) aimed specifically at developing an understanding, not only of how this Nation could employ high energy laser technology in space to assure survival of the National deterrent assets, but to recognize the potential threat posed by the development of this technology by any foreign power. Guided by the technical focus provided by the UDT program, DARPA's FY 1977 high energy laser program is investing in research on propagation effects, lightweight apertures, and high energy visible lasers to establish the feasibility of such alternatives. Additional unconventional missions of high energy lasers are being explored in FY 1977. Finally, during FY 1977 and FY 1978, we will be testing the feasibility of using the inherent accuracy of laser radars to do precise handover.

c. High-Stealth Sensors. The objective of this program is to significantly reduce the vulnerability of aircraft radar systems to enemy exploitation and attack by reducing the ranges at

which the radar electromagnetic signals can be intercepted, located, classified, and attacked. This is accomplished by reducing the peak radiated power level, and by compensating for this by applying time, frequency, and space diversity techniques.

The Low Probability of Intercept (LPI) fire control radar program established in FY 1976 will complete breadboard design specifications in December 1976 and prototype flight testing in FY 1978. This system will validate that LPI features can be integrated into a modern fire control without sacrificing target detection range and without a significant weight, volume, or cost impact. This program also includes development of a high-speed analog radar signal processor which incorporates the best features of high-technology electronic components. Such a processor may significantly reduce the cost of future Low Probability of Intercept Radar (LPIR) systems. The extension of this technology for LPI attack radars, terrain-following radars, and radar altimeters is being undertaken in FY 1977.

d. Advanced Missile and Undersea Target Acquisition (AUSEX/SIAM). With the exception of speed and deception devices, our submarines have no active defense in the event that they are localized and attacked by aircraft. While the probability of initial detection remains low, the high value of our submarines makes the potential penalty too great, and the recent Soviet build-up in ASW aircraft cannot be ignored.

DARPA is developing the technologies necessary to provide a self-defense capability for submarines against aircraft. This includes experiments to determine the feasibility of detecting aircraft noise at significant ranges with underwater sensors and a project to demonstrate a self-initiating, anti-aircraft missile (SIAM), which can rise from a submerged launch to search, acquire, and attack ASW aircraft and helicopters operating over or near the submarine. Recently a large-scale experiment was conducted north of the Hawaiian Islands demonstrating aircraft detections and collecting extensive underwater data on fixed wing aircraft and helicopters. These data will be used to develop the advanced processing techniques required to exploit the acoustic vulnerability of aircraft.

Another major accomplishment was the successful demonstration, the first of its kind, of a dual mode sensor for the autonomous SIAM missile. This dual mode seeker will give the missile an all-weather capability and inherent resistance to counter-measures.

In the next three years, we will demonstrate the missile in full free flight, and the capability to detect and track aircraft from beneath the surface at significant ranges. These advances are intended to form the basis for advanced development of a submarine air defense capability by the Navy.

e. Biocybernetics. Another approach to enhancing the interaction between man and machine is exemplified by DARPA's research in biocybernetics, which is an effort to provide the basic

research foundation for the enhancement of military job performance in conjunction with sophisticated equipment. There have been major accomplishments in the interpretation of neural events and of the neural state. Three laboratories have independently demonstrated that it is possible to identify specific words in a neural language. "Word" in this instance means an identifiable set of waveforms in an electric brain wave trace. Five such words have been identified and have been used with 90% accuracy to interpret neural events. Some specific cognitive events that can now be inferred form the interpretation of neural events include: lapses in vigilance due to fatigue or boredom; attention to information flow and attention to particular sensory stimuli; uncertainty and the need for additional information for solving problems; correctly diagnosing when a decision has been made and anticipation of related action; and the apparent perception of colors and patterns. These advances have been demonstrated in laboratory settings with civilian personnel performing simple tasks. Further, it has become possible to interpret neural signals while people perform more complex tasks in a laboratory--tasks analogous to military jobs such as aircraft control.

f. X-Wing VTOL Aircraft. The X-Wing aircraft offers the potential for combining in one flight vehicle the advantages of the efficient vertical take-off and landing performance of the

helicopter with the high subsonic speed capabilities possessed by fixed wing aircraft. This is achieved by the use of a four-bladed rigid rotor that can be stopped at a forward velocity that allows the aircraft to sustain flight in a fixed wing mode. The ability to accomplish efficient rotary and fixed wing flight is achieved by a unique circulation control blowing over the edges of the rotor blades which furnishes lift and control for all modes of flight. Principal advantages of this concept over other non-rotor VTOL aircraft are high payload-to-power ratios, good hover/low speed handling qualities, low downwash velocities and temperatures, and low noise levels.

At concept inception, a number of high-risk, key technology areas were identified and DARPA initiated a program to resolve these issues through wind tunnel experiments, analyses, computer simulation, and design studies.

The feasibility of the circulation control technology has since been demonstrated by a six-month theoretical analysis and by almost 1000 hours of wind tunnel model testing. The preliminary design of a flight demonstration vehicle has been accomplished, and we have defined the requirements of the circulation control system for lift and vehicle control. These efforts have produced a better understanding of the complex aerodynamic and control phenomena associated with the vehicle and have demonstrated the feasibility of the concept. The use of advanced composite materials in the rotor blade design is key to avoiding aeroelastic problems normally found in swept-forward

airfoil concepts. The next phase of the program will involve a full-scale wind tunnel test of the rotor to include a breadboard of the circulation control system. Finally, if the risk reduction program is successful, a flight testbed will be assembled to demonstrate the X-Wing vehicle in FY 1978 and FY 1979.

g. Compound Semiconductor Process Technology. Infrared surveillance systems, as well as microwave radar and communication systems, have reached a stage of sophistication where they require information processing capabilities which cannot be met with silicon integrated circuits. Consequently, DARPA is conducting a major program to develop the process technology required to fabricate integrated circuits of gallium arsenide, a semiconductor material which offers high speed and low power capabilities suitable to these advanced systems. Emphasis will be on establishing reproducible procedures for forming complex device structures by the multiple implantation of dopant ions directly in semi-insulating gallium arsenide substrates. The feasibility of this approach has been demonstrated by DARPA-sponsored gallium arsenide research in FY 1977 and prior years.

h. New Metallic Microstructure. The best superalloys for use in metal gas turbine engines are made from alloys developed in the late 1950's. The drought in superalloy development since then has persisted because we have reached the limits of the

conventional processing techniques in which turbine blades are forged from superalloy ingots. As a large ingot slowly solidifies, large crystals form within it, trapping impurities at the boundaries between these crystals. These boundaries form a network of not only weak material but also sites at which corrosion is later initiated. DARPA has begun a major new program, the goals of which are to develop new processing techniques, which will result in superalloys which can operate at temperatures 100°F higher. These new superalloys will permit increasing turbine inlet temperatures with resulting reduction in gas turbine fuel consumption by at least 10% and a performance improvement of at least 15%. Overall savings to the F-100 engine program, for example, with impact occurring in 1981, could be as much as $120 million.

The approach being taken to achieve these impressive gains is to start the forging process with powders rather than with ingots. DARPA is developing a process whereby a ton of extremely homogeneous powder can be produced per day. This powder is formed by the rapid freezing (10^5-10^6 degrees/sec) of small liquid droplets of the superalloys. By preparing the starting material for the forging operation in this way, large crystals are eliminated and impurities become frozen into the powders. Not only should this result in a 100°F temperature improvement, but we expect the low cycle fatigue life to be considerably extended, resulting in reduced life-cycle costs for jet engine turbine blades and disks.

Achievements under this program in FY 1977 have been so encouraging that potentially high payoffs have been identified in applying rapidly solidified powder technology to other alloy systems of importance to DoD. By suppressing the formation of coarse second phases, segragated impurities, and irregular microstructures, the prospects for developing structural alloys with higher strength, higher fracture toughness, improved corrosion resistance, and extended fatigue life seem especially promising. Therefore, an objective of the DARPA program in FY 1977 and beyond is to extend the base of this promising new technology by both developing bench-scale powder makers for exploratory research and by pursuing substantial improvements in alloy microstructures and properties for aircraft structure and tooling applications.

i. Computer Science. Information Processing and Computer-Communications Technology continues to be an area of major emphasis in DARPA. The rapid progress in low-cost hardware developments coming from industry provides a powerful base from which to attack DoD-unique problems. For example, the capability to automatically interpret imagery has been sought for almost a decade. Recent research results in the computer sciences have led to increasing optimism for this long-term goal. First, the revolution in microprocessors indicates that the computing power required to analyze images in small, cost-effective systems at real-time rates is at hand. Second, human vision research has

produced many new insights for the automatic analysis of imagery. Third, computer science research has successfully demonstrated many scene analysis techniques that automatically convert image data into symbolic information. The DARPA Image Understanding Program will capitalize on this background to build, within the next four years, a concept demonstration system that can automatically find objects of interest in images.

j. Distributed Sensor Network. Conventional surveillance systems such as radar and passive satellites are sophisticated but expensive and it is not cost-effective to deploy a sufficient number of them to survive direct attacks. We rely heavily on surveillance systems during both peacetime and wartime, yet the most effective of these systems often provide the most vulnerable targets to enemy assault. A few key strikes could seriously reduce, or even destroy, our tactical surveillance capabilities in a number of areas.

The emergence of packet radio as a viable tactical network communication system and the availability of low cost sensors and microprocessor technology suggests that a fundamentally different approach using many low-cost unsophisticated sensors can be taken which will achieve a system that is potentially far more survivable and which may achieve far more capability for improved target detection, reduced false alarm rate, etc. These attributes could be obtained at significantly lower cost for the entire system.

We are investigating this concept in the context of a distributed sensor network and exploring the coordinated use of multiple sensing techniques. Emphasis in FY 1978 will be on the development of basic system concepts, technical approaches, and tradeoffs.

k. Air-Air Defense Systems. With the advent of miniature high-speed computers and solid state radar transmitters, a much improved new generation of air-air missiles is possible. DARPA has undertaken an effort jointly with the Air Force to assess the potential advantages of these new technologies in an air-air missile role by developing conceptual designs and evaluating the performance and cost of these designs. Preliminary results to be substantiated by simulations and subsystem test results indicate that it may be possible to replace the current 500-pound all-weather missiles. The lightweight solution is possible by combining advanced aimable warheads, terminal seekers, low cost guidance units plus microprocessors capable of optimal use of seeker, target, and end-game geometry data. At the end of the current assessment, DARPA will invest in the technology development and demonstration that may permit subsequent development of a common Air Force-Navy missile.

l. Sanctuary Radar. A testbed has been established for experimental investigation of bistatic radar techniques for situations where the radar transmitter is situated at some safe distance from both the receiver and the target. The objective is to determine the feasibility of bistatic radar systems for a wide variety of missions. The program will initially measure target and clutter characteristics for a wide range of parameters for the

surface-to-air search and track mission. This will be followed by air-to-air search and air-to-surface search and track experiments.

m. Nuclear Test Monitoring Research. While it doesn't represent the same type of effort as others in this section, nuclear monitoring research is providing the technical groundwork for negotiations which could lessen tensions and enhance security. In the late 1950's and early 1960's, it became evident that the US lacked adequate capability to verify compliance by other nations with the terms of nuclear test ban treaties then under consideration. By interagency agreement, the DoD accepted responsibility for research to improve national detection capabilities, and this mission was assigned to DARPA. Since that time, DARPA has been a primary source of technical information for the Nation's policymakers in conducting negotiations on nuclear test limitations. This information was an important element in successful treaty negotiations in 1963 banning nuclear explosions in the atmosphere, underwater, and in space. Research continued after that time to improve national capabilities in compliance with "Safeguard Number 4," as pledged by the President to the Senate as a condition prior to ratification of that treaty. This continuing research has led to numerous improvements in the US operational detection system, and once again provided essential negotiating information used to establish verification requirements which became part of the Threshold Test Ban Treaty of 1974, and the Peaceful Nuclear Explosion Treaty of 1976.

Earlier phases of the research had largely been completed by 1973, and a new program was initiated at that time to solve the problem of discriminating between underground explosions and earthquakes of similar size and seismic characteristics. Work was also initiated on means to identify disturbances whose signals are partially obscured by seismic waves from large, nearly simultaneous earthquakes--a serious problem for any comprehensive test ban since it currently causes a significant number of seismic disturbances annually to be unidentifiable either as earthquakes or as underground nuclear explosions. This work required upgrading a number of existing seismic stations in US and foreign localities to acquire the data to test results of theoretical studies. This network of high-quality stations will have been essentially completed by the end of FY 1977. The major emphasis in FY 1978 will be directed to the application of the data in research leading to improved seismic discriminants. The heretofore unavailable high-quality world-wide network data will provide the means for studying new aspects of seismic wave generation and propagation and applying the knowledge gained to the discrimination problem. The seismic Data Management System developed to handle the unprecedented volume of network digital seismic data will be fully operational by FY 1978 permitting a demonstration period during which the full potential of the system for research applications can be evaluated and the results used in formulating specifications for a possible future optimum world-wide seismic surveillance system. Engineering studies begun in FY 1977 to design

a minimum-manned seismic station to obtain high quality data in areas where operators are poorly trained or unavailable will be completed in FY 1978. Efforts aimed at development of an optimum surveillance system will provide the means for meeting the more severe surveillance capability requirements of the future as further limitations on nuclear testing lead to lower yield thresholds.

While the major thrust of the nuclear monitoring research effort has continued to be directed to problems associated with verifying compliance with a Comprehensive Test Ban Treaty, the Threshold Test Ban Treaty and associated Peaceful Nuclear Explosions Treaty have posed a new set of problems associated with the accurate estimation by seismic means of the yields of underground nuclear explosions and the development of techniques for countering attempts at evading these yield limits or exploiting so-called peaceful nuclear explosions for gaining weapons-related benefits. In FY 1975, theoretical and experimental studies were initiated to develop an accurate prediction capability for seismic wave generation by underground nuclear explosions. Development of this prediction capability will be well advanced by the end of FY 1977 permitting a quantitative estimate of the effects of various near-source and propagation path effects on observed seismic waveforms. These results should permit a considerable reduction in yield estimation uncertainties and, with the improved quantitative understanding of the seismic wave generation process, will provide the basis for identifying

and assessing the potential application of schemes for yield evasion and the development of appropriate counterevasion techniques.

Our current plans show a continued decline in funding through FY 1979, after which time the research necessary to satisfy existing requirements in Nuclear Test Ban Treaty monitoring will have been essentially completed.

III. ACCOMPLISHMENTS

This section is intended to provide a capsule report on the output and the dynamics of the DARPA program during the past year. It is by no means a complete statement of all activities but, rather, a selection of those we consider worthy of special note. The period covered includes the FY 1976 - 1977 transition quarter and part of FY 1977. Four categories of accomplishments or actions are presented· (1) technological achievements, (2) programs transitioned for follow-on research or systems applications by others, (3) programs terminated, and (4) new ideas or initiatives.

A. Technological Achievements

1. High Power Electrical Lasers. The DARPA high power electrical laser effort is concentrated on the development of electrically-excited ultraviolet/visible lasers. During the past year rare gas halide lasers have been advanced from the one joule per pulse level to over 350J with a 10% electrical efficiency. The breakthrough of operating visible pulsed lasers in the hundred of joules regime provides substantially increased confidence that such laser devices are feasible.

2. Anti-Submarine Warfare (ARC-FME). In FY 19TQ, the DARPA Acoustic Research Center (ARC) located at Moffett Field, California, attained full operational capability. We conducted an extremely ambitious and highly complex acoustic surveillance experiment using the ARC as the central experiment control and data processing center. Several major firsts were achieved during this experiment:

(1) In order to do inter-array processing we developed and used for the first time a commercial satellite communications link to get the towed array data from the ship to the ARC; (2) Over 20 digital computers, including ILLIAC IV, were used during the experiment; (3) ILLIAC IV was used in a secure mode; (4) The ARPANET was also used in a secure mode for the first time, linking the secure data processing facility at the Naval Undersea Center, San Diego, California, with the ARC; (5) Three different inter-array processing techniques were used to track both cooperative and uncooperative targets. Acoustic projectors were used which transmitted simultaneously at different frequencies a strong and a weak signal. Results for the strong signal demonstrated that signals received could be effectively combined to reduce accurate localization uncertainty. An extensive analysis of the weak signal data is being conducted at the ARC in FY 1977 to precisely quantify the performance of the three different algorithms against quiet submarines.

3. Armored Combat Vehicle Technology. A total of 550 shots have been fired from the DARPA 75mm automatic cannon at various elevations up to 45° at a rate of up to two shots per second. Barrel life is predicted to be greater than that of the current M-60 tank gun, even though the gun is fired at about ten times the rate of fire of the 105mm tank gun (four times the tube life of German 120mm gun). Another significant achievement is the development of the long rod penetrator ammunition for the 75mm gun.

4. Hostile Weapons Location (HOWLS). The feasibility of applying new technology to the age-old problem of detecting artillery and mortar launchers has been demonstrated. An experimental model of a passive Infrared (IR) Mortar Locator has been built and field-tested against live mortar firings at both Camp Edwards and China Lake. The feasibility of combining passive detection and laser ranging was demonstrated, and mortars were automatically located. Calculations of the thermal signatures of shells show that this range can be extended and that the device could also detect and locate enemy artillery batteries. In its final form, the IR Mortar Locator will be low in cost, jeep-portable, and will give the forward area commander the capability to detect and locate enemy mortars at ranges greater than their maximum firing range.

5. Low Data Rate Packet Speech Communications. Speech compression techniques have been developed which permit high quality packet speech transmissions at average data rates of less than two kilobits per second. Point-to-point packet speech transmissions and conferenced speech over the ARPANET between four parties in geographically distributed locations were previously demonstrated. The importance of this technology is that it will permit the achievement of an integrated data and voice computer-communications network. Such a network is a 1985 goal of the Defense Communications System. Through internetting, the packet speech technology also permits graceful speech communications possible between speakers served by different networks.

6. Secure Communications Over the ARPANET. DARPA-developed devices permitting point-to-point secure communication over the ARPANET were placed in operation in April 1976 and have operated continuously since that time. This work achieved an end-to-end security capability which permits the use of the ARPANET to support a number of classified experiments in computer-communications without resorting to conventional techniques of physically securing switches and lines at prohibitively high costs. The ARPANET is the technological base for AUTODIN II, the future classified military computer-communications network which has scheduled initial operating capability in FY 1979. The availability of this secure capability provides an important command and control technology option and a significant step toward providing end-to-end security for AUTODIN II.

7. Text Material Abstraction by Computer. Abstracts of text material are currently produced either by the writer of the original material or by a reader/analyst. Computer scientists have been investigating the mechanisms of natural language to better facilitate automatic text abstraction and analysis, and for better human factors at the man/machine interface. Recent successes in this DARPA technology development have enabled the demonstration of a computer program that can read newspaper stories about accidents, produce abstracts of those stories, and answer questions about the accident. This technology could greatly facilitate the processing of operational and intelligence messages in command and control systems. Many command situations become

sluggish as a result of the heavy message traffic loads, especially in a crisis when the command decisions are most crucial. Message abstraction capabilities will enable the receiver to prioritize his messages before reading them. Current systems only allow the sender to assign a priority.

8. Ground Packet Radio Technology. A small experimental test network was established with five packet radios. Terminal-to-computer communications were demonstrated among both fixed and mobile sites at ranges up to 25 miles and as close as several feet. The ability to communicate over a three-to-five hop path was demonstrated. During the next 19 months the test network will grow to 37 packet radios, permitting realistic tests of multi-terminal contention, multi-hop operation, and network self-organization. An upgraded packet radio is under development which will incorporate and test anti-jam and low-probability-of-intercept capabilities.

9. Advanced Decision Technology Program. This program has generated products that have been applied in three distinct areas:

a. System Evaluation Methodology. A formal, versatile, and powerful new methodology for evaluating alternative designs of complex defense systems has been developed and tested. Prior to this innovation, such evaluations were performed largely by subjective analysis and judgments which were often based on insufficient information, incomplete and unweighed criteria, and inconsistent logic. The new methodology, which is based on

classical utility theory, permits the orderly and logical development of a single numerical index of worth for the alternative system designs, each of which varies in terms of cost and in multiple dimensions of performance. This methodology has proven successful in evaluating alternative designs for the Hostile Weapons Locating System (HOWLS), in screening contractor proposals for a design-to-cost procurement for the US Navy, in assessing proposed new radio system designs for the US Army, and for design definition of the US Navy Shipboard Intermediate Range Combat System (SIRCS). The methodology has been implanted through generalized minicomputer software models that have reduced the time required to tailor a model to a specific application by a factor of four. Follow-on efforts will be directed toward tailoring this evaluation methodology as a candidate doctrine for Federal procurement.

b. Quantitative Indications and Warning Model. A quantitative indications and warning capability has been developed and placed in experimental use at Headquarters, US Pacific Command. This new minicomputer-based methodology permits staff intelligence analysts to structure and continually update threat estimates on the basis of evolving information about relevant political and military developments. Prior to this merging of decision theory and computer technology, such indications and warnings were structured and assessed by purely subjective means and judgments. A follow-on effort that is being explored and evaluated by the US European Command deals with indications and warnings which

indicate the level of threat of a Soviet non-reinforced attack directed against NATO.

c. Minicomputer Technology as a Decision-Aiding Medium. A series of decision-aiding models which exploit minicomputer technology has been placed in experimental use at Headquarters, US European Command and at Headquarters, US Pacific Command. The decision models under evaluation at the European Command permit the staff operational and intelligence analysts to develop intelligence estimates and operational courses of action based on complete and consistent quantitative methods. The decision models being used by the Pacific Command are used in the intelligence indications and warning application. The personal control and personal access afforded by the use of minicomputers in these applications is greatly preferred over the alternative means of gaining support--through large-scale computers.

10. Improving Software Engineering Practices by Utilizing Computer Network Communications. The only widely used and moderately effective technique for coordinating the efforts of government personnel and contractors from different geographic locations when they must work together to design, develop, and build a large software system was to move them to the same place. Travel to the development site was also the only effective way for someone planning a new computer hardware/software system to gain hands-on experience with new software capabilities, and the only way for maintenance organizations to verify the symptoms

reported on software discrepancy reports. Using the ARPANET, the most important technical barriers to the use of networks by software developers have now been overcome, and a solid body of evidence built to support the use of computer networks for software development and maintenance. Specifically--

- The ARPANET was used to develop at least three major software systems (National Software Works, Packet Radio, Advanced C^3 Testbed). In each case, some of the contractors were on the East Coast and others on the West Coast.

- The ARPANET was used in the planning phases of the Advanced Command Control Architectural Testbed and the Military Message Experiment at CINCPAC, and also by the DoD High Order Language Working Group to coordinate the specifications of DoD requirements for higher order languages and to evaluate how well existing languages meet those requirements.

- Several widely used software systems were maintained and distributed to user sites via the network. It is common for a software problem in a computer attached to the ARPANET to be diagnosed and corrected by a specialist hundreds of miles away within a few hours of its discovery.

- The system integration milestone was achieved in the effort to develop a software tool repository and environment for evaluating innovative software capabilities on the ARPANET. The basic framework of this National Software Works is in place, and an initial repertoire of tools installed.

- Navy laboratories, major Air Force Systems Command installations, and DARCOM sites are all being connected to the ARPANET to access and evaluate software development and maintenance tools.

11. Engine Life Prediction. Non-metallic particles can now be detected in oils through use of a new ferromagnetic fluid in conjunction with a standard ferrographic oil analysis. Non-metallic contaminants often cause premature failures of submarine and cannon seals. The detection of these particles, heretofore impossible, now permits use of the ferrograph to detect wear in these and other systems critical to the Defense Department.

12. Quantitative Non-Destructive Evaluation. A self-consistent scheme for ultrasonic calibration has been developed which introduces three important new concepts. These are: (1) an ultrasonic standard which is a solid state version of the familiar "sphere in a water tank," (2) a quantitative figure-of-merit determination for the transducer, and (3) theoretical curves matched to the standard which form a basis for the calibration. Industry has until now lacked suitable ultrasonic calibration standards which are both universal and understandable.

13. <u>High-Rate Powder Development</u>. Metallic powders can be produced in large quantities at cooling rates exceeding 100,000°C per second with particle sizes of 50 micrometers or less. The proof of this technology will enable the DoD to produce superalloys having superior properties at higher temperatures, thus enabling better performance of jet engines and other high-temperature systems.

14. <u>Superplastic Forming of Steels</u>. The discovery last year that high-carbon steels can be made superplastic and therefore easily formable, has now been extended to steels having lower carbon contents. This provides the prospect of applying new "near net-shape" fabrication processes to a wide variety of steels extensively used by the DoD.

15. <u>Video Bandwidth Compression</u>. Techniques have been developed to transmit good quality TV using only 5% of the bandwidth normally required for standard TV signals. Bandwidth reduction of this magnitude is essential so that spread spectrum techniques can be used in TV data links for RPVs and precision-guided munitions to provide protection against enemy jammers. We have carried out extensive experimental and theoretical work to evaluate various image transformation methods, analog and digital devices for transform calculations and the quality and utility of the transformed images. Hardware is now being built to perform this bandwidth compression, in real-time, on a single printed-circuit card weighing less than one pound.

16. Anti-Jam Data Links. Work in the past year has demonstrated that spread spectrum modulation and null-steering antennas could be combined to give protection in a small, lightweight, low-cost modem. Continuing R&D has shown that the performance of the antenna can be improved significantly by adding circuitry which distinguishes between desired and undesired signals, and that added protection can be realized by adding an adaptive filter (Baghdadi loop) to the front end of the receiver. With these minor additions, this expendable data link package will perform better than the large, expensive, fixed-plant systems in use today.

17. Seismic Data Management System. The major components of a Seismic Data Management System have been completed. These include: a Communications and Control Processor to receive seismic data from remote sites, monitor the quality of that data, and forward it to processing or storage devices; a Mass Data Storage Device capable of on-line storage of 10 billion samples of seismic data; and a Network Event Processor which reduces the data from these devices to yield seismic location and source identification parameters. Although some modifications are still in progress, this system provides means for developing and testing automatic data processing procedures related to nuclear test monitoring and efficiently performing research experiments on large, well-organized data bases which give rise to statistically stable, easily reproducible results.

18. Extended-Wavelength-Response Photocathode. Operation of a photo-sensitive, compound-semiconductor, heterojunction structure in the transferred electron mode has demonstrated for the first time photoemission at useful sensitivities out to photon wavelenghts of 1.7 microns. This compares to present photoemissive structures which are sensitive only out to approximately 1 micron. The longer wavelength response will enable us to make use of sky glow radiation in the 1.0 - 1.7 micron range region for imagery. Such photocathodes may permit a factor of three increase in image intensifier viewing range without loss of spatial resolution.

19. Gallium Arsenide Integrated Circuits. The process technologies for growing semi-insulating gallium arsenide and subsequently forming basic integrated circuit logic gates in this material by ion implantation have been demonstrated for the first time. These process steps form the basis for the only practical approach to make planar integrated circuit structures in gallium arsenide, which will perform at speeds an order of magnitude faster and power levels an order of magnitude lower than can be achieved with silicon integrated circuits. Development of gallium arsenide circuits will be crucial to establishing the capability to process the massive amounts of data which will be generated by strategic and tactical surveillance systems now under development.

20. Adaptive Information Selection. A new method for automatic message selection in command and control (C^2) has been demonstrated and transferred to the Navy for further evaluation.

The choice of important messages from an average of more than 600 messages/hour during crises is a significant C^2 problem. Manual selection methods using "key word" approaches usually choose eight or nine irrelevant messages for each relevant, important message. The new automatic information selection method develops message choice criteria by observing and learning the criteria people use in manually selecting important messages, while working faster, less expensively, and with fewer errors. The new method selects messages with 95% accuracy.

B. Programs Transferred to Others

1. Teal Feather. The objective of the completed DARPA Teal Feather program was to develop and demonstrate special communications. An experimental set of equipment was developed and tested in conjunction with the Naval Electronics System Command (NESC), PME 107. The Field tests were successful and the concept and equipment provide the Navy with a required operational capability not currently available elsewhere. The Teal Feather equipment has been transferred to NESC to be used on a selective basis for fleet operations and special missions while the Navy develops a full-scale capability of its own.

2. Project ARIENNE. Project Arienne developed a system for low-probability-of-intercept acoustic communication from submarines at very long range. The concept was successfully demonstrated on an operating submarine. The Navy is producing a number of systems for deployment. The system will enable low data rate

communications from our submarines without increasing their detectability by nearby Soviet submarines or other acoustic sensors.

3. GPS Tactical Missile Guidance. The GPS Tactical Missile Program investigated concepts for using GPS for guidance of medium-to-long range tactical missiles such as Pershing, Air-delivered Stand-off Missile, MGGB, and Cruise Missiles. The investigation indicated that Tactical Missiles using GPS autonomously would be highly susceptible to jamming. A hybrid GPS inertial guidance concept is required to maintain sufficient accuracy to impact at the target. Our studies investigated various means of providing low cost inertial components and micro-computers for accomplishing both the inertial and radio navigation computations. The program demonstrated general feasibility of the hybrid concept. It was transferred and absorbed by a new Air Force initiative to apply GPS to Tactical Missiles. If successful, the program will yield new missile guidance systems that will be highly accurate and significantly lower in cost ($25-50 thousand) than existing fully-inertial or terrain navigation systems.

4. Pulsed Chemical Laser. The DARPA/Navy pulsed chemical laser program was initiated in FY 1976. Key physics experimental demonstrations with goals of 100 joule/liter at 100% electrical efficiency, repetitive flameout at 100Hz at 50% mass utilization efficiency, and repetitive pulse acoustic suppression required for diffraction-limited beam extraction will be completed during FY 1977. The Navy will then initiate a repetitive pulse demonstration laser incorporating all of these technologies during FY 1978.

5. Fleet Defense Aids. The Fleet Defense Aids program concentrated primarily on: 1) an overall assessment and modeling of the Soviet Ocean Surveillance System (SOSS) and 2) a concept for causing errors in target location. A computer model of the integrated SOSS system was formulated and transferred to the Navy for continued development and application. The Navy recently awarded a contract for continuing its development.

6. Military Operations in Built-up Areas (MOBA). The MOBA program illuminated important deficiencies and uncertainties in our capabilities for urban warfare and explored improvements in indirect and direct fire weapons for this application. A manual gaming model useful in training as well as for evaluating weapons systems was developed and transferred to the Army. The Army initiated tests of weapons to determine their performance characteristics in the urban environment, stimulated by and based upon the DARPA results. Additionally, the Army has expanded its treatment of urban warfare in officer training courses and in its new Field Manual. DARPA sponsored a project to collect information on built-up areas in a region of the Federal Republic of Germany and to prepare exemplary maps that incorporate terrain structural features important to military operations. These maps include features of buildings as well as vegetation and are useful in analyzing possible enemy avenues of advance and defensive counter operations. As a result of this DARPA program, urban warfare is now getting the attention it deserves after being

neglected in weapon development, testing, training, and exercises since World War II. If brought to fruition, a greater capability and preparedness for urban warfare will significantly improve our NATO defenses against the conventional Warsaw Pact threat.

7. Segmented-Magnet Homopolar Machine. The segmented-magnet (SEGMAG), homopolar machine development has been transferred to the Navy for follow-on hardware development. This technology offers highly compact (20 to 25-fold improvement in power density over conventional machines) electrical machinery for ships, torpedoes, and other propulsion applications. DARPA is continuing research on solid-brush current collectors to provide very high current capacity with low power loss and very long life for innovative SEGMAG machine designs.

8. Ferrous Die Casting Program. Two new concepts developed by DARPA for extending die casting processing to cast irons and high alloy steels, called "Thixocasting" and "Rheocasting", are being transferred to the Army for the demonstration of manufacturing feasibility and cost reductions for selected high-volume parts. This technology has shown the potential of greatly reducing manufacturing costs by forming complex parts to "near-net shape" with a machine-like finish, increasing die life, process yield, and production rates, and reducing both scrap recycle and life-limiting defects.

9. Manpower Research. The manpower research program has produced comprehensive, quantitative defense manpower models, making possible, for the first time, accurate assessment of the

impact of personnel policy decisions. Prior techniques were qualitative or were not comprehensive, sometimes overlooking seemingly unimportant factors that were, in fact, significant. As an example of the importance of the new approach, the "one-percent kicker" in retirement pay was identified as a large and unnecessary defense cost. Subsequent action by the Congress led to the elimination of the "one-percent kicker," resulting in estimated savings over the next several years of $2.5 to $3.0 billion. This new technical capability has been transferred to the Office of the Secretary of Defense, Manpower and Reserve Affairs, and a new Manpower Research Institute is being created to exploit, apply, and extend the capability developed in this DARPA program.

10. Satellite Radar Altimetry. As a means to provide geodetic and gravitational information needed for accurate missile aiming and guidance, DARPA initiated work through the Naval Research Laboratory for the development of a satellite-borne radar altimeter. This device gives promise of providing capability to measure deflections from the vertical and the figure of the earth at sea to ten-centimeter accuracy, to do this at lower cost than from surface ships, and to obtain such information unobtrusively in inaccessible or remote areas of the oceans. The Navy will share in the cost of this work in FY 1977 and will continue development of the device through its own resources in FY 1978.

11. <u>Iranian Long Period Array</u>. The recently completed Iranian Long Period Seismic Array, made up of newly developed DARPA seismometers, was transferred to the Air Force at the end of FY 1976 (TQ). Seismic data from the individual seismometer sites is telemetered to a central recording facility in Teheran for processing and further transmitted to the United States to be used in joint DARPA/Air Force seismic verification research programs. The array is operated by the University of Teheran under contract to the Air Force, and Iranian seismologists have access to the data to pursue their own research interests.

12. <u>Ceramic Turbine Materials And Processing Technology</u>. Beginning in FY 1977, the DARPA "Brittle Materials Design, High Temperature Gas Turbine Program" at Ford Motor Company will be transferred to the Energy Research and Development Administration (ERDA). While DARPA's goal remains the establishment by a short-term demonstration (200 hours) of ceramic gas turbine engine that will establish the usefulness of brittle materials for demanding DoD applications, ERDA's objectives, based upon the progress achieved under the initial DARPA programs, are focused on continued development of ceramic gas turbine engines to meet long-term durability goals. In order to accommodate both of these objectives, the scope of the FY 1977 DARPA portion of the program is oriented toward evaluating the reliability of state-of-the-art ceramic components, and the ERDA portion of the program is concerned primarily with improving the durability of ceramic turbine rotors through continued longer-term materials and processing research.

C. Programs Terminated

1. X-Ray Laser. This program was technically very successful: Coherent radiation has been observed at 380 Å under the jointly funded DARPA/NRL research task, and even further progress was probable. However, in continually reviewing the military significance of the work and comparing it with other projects, it became apparent that, even granting technical success, any military impact was at best indirect, long-range, and would require extensive research and exploratory development to exploit. We have, therefore, terminated the program and have recommended further that research in this area be funded by the NSF.

2. STAR Program. The DARPA STAR program analyzed methods of combining real-time surveillance data for use by strategic decision-makers in a processing constrained mobile command post. This effort was terminated in FY 1977 after initial experiments showed that, while the concepts were feasible and useful, the prime issues were doctrinal and non-technological.

3. Liquid Propellant Gun. Exploratory development of a 75mm Liquid Propellant Automatic cannon for combat vehicle application was terminated after fundamental difficulties were encountered in firing the gun in a single shot mode with dynamic loading of the liquid charge. The automatic cannon program was initiated in FY 1973 with effort on both a solid propellant gun and a liquid propellant gun. Both efforts were scheduled in phase with the design and fabrication of an experimental fire

control system and a combat vehicle testbed for demonstration of the total weapon system concept. In view of the great success of the solid propellant cannon, which is now being fired in the fully automatic mode and of our assessment that extensive research is needed on liquid propellants and their combustion physics before the gun development effort can be resumed, we will terminate DARPA's effort in FY 1977. We are working closely with ODDR&E and the Services' laboratories on the plan for a long-term research effort on liquid propellants for a broad range of gun applications.

4. AEQUARE Long-Range Mini-RPV. The AEQUARE RPV concept is a miniature remotely operated aircraft that can be carried in a pod with wings folded on a manned tactical aircraft. The RPV can be launched by the aircraft and remotely operated from the same aircraft or from a farther-removed ground station with data relay by the launching aircraft. With this system, the manned aircraft can stand off at a safe range from enemy air defense units, send in the RPV to locate and designate rear-area and interdiction targets, and launch precision guided munitions to strike these targets. The RPV would use optical/IR equipment for remote control and target acquisition and would carry a laser for target designation. Although we successfully demonstrated launch from an F-4 and deployment of the RPV from its pod, the experimental system was not sufficiently reliable to demonstrate the payloads and mission without a major advanced development effort to achieve acceptable reliability. In view of the disproportionate costs to demonstrate the total concept and declining Air Force

interest in the operational payoff, the program was terminated and the equipment shelved.

5. Lithospheric Communication. The program to investigate the feasibility of using the lithospheric layer beneath the earth's crust for a naturally hardened communications channel was terminated in FY 1977. The critical experiment of the program was to verify predictions that the resistivities in the channel were high enough for efficient long distance strategic communication. The experiment, successfully conducted off the west coast of the US, did not provide positive results and the activity was therefore terminated.

6. Speech Understanding. Although interest in the problem predates the computer, during the past ten years computer technology has revolutionized traditional approaches to machine speech recognition. DARPA research applied many new techniques from the artificial intelligence area of computer science in addition to major ideas from digital signal processing, for computer representation and purposeful manipulation of the syntactic and semantic structure within the input speech. These new ideas enabled DARPA researchers during the past year to achieve the first successful recognition of continuous sentence, rather than isolated word, speech. The best system achieved better than 90% semantic (meaning) sentence accuracy on a vocabulary of 1000 words. The system ran in twenty times real-time, but minimal research effort was expended to achieve real-time performance. With this achievement, DARPA-sponsored research has been completed and the program terminated. The results are

available to the industry and the Services for follow-on development of real-time, low cost hardware for specific applications.

D. New Ideas/Initiatives

1. Laser Tracker. As the DARPA development of a ground-based laser radar has evolved, other applications utilizing the inherent precise angle and range information available from a laser radar tracker have been analyzed. The concept of a laser detection and ranging (ladar) sensor system capable of providing extremely precise tracking and prediction data has been investigated. It was determined that laser radar possesses the capability to track with short dwell times and sufficient accuracy to provide small prediction error volumes. In FY 1977, a series of experiments will be designed using the existing DARPA facilities at Maui, Hawaii, to demonstrate and verify ladar tracking and handover accuracy. Experiments to verify reference system approaches to ladar platform alignment will be defined.

A major new initiative planned for FY 1978 will be a jointly-funded experimental demonstration program with the US Army. Specifically, a laser radar experiment will be conducted in which existing facilities, including the laser system at the DARPA Maui Optical Station, will be modified as required.

2. Passive Detection of Aircraft. Passive detection of aircraft would provide an important complement to the current active radar by eliminating or reducing the ability of hostile aircraft to avoid detection through electronic countermeasures.

Using sensor technology along with recently explored signature and propagation phenomenology, a utility analysis was completed, a sensor designed, and the basic phenomenology of the propagation of aircraft signatures over very long atmospheric paths was theoretically analyzed. These analyses showed sufficient promise to initiate in FY 1978 an experiment to demonstrate feasibility. A sensor will be fabricated and incorporated into the DARPA-Maui Optical Station (AMOS) located at 10,000 feet on Mt. Haleakala. Long path propagation measurements will be performed, correlated with atmospheric conditions, and utilized to predict performance. Successful completion of this phase of the program will be followed by initiation of a proof-of-concept experiment for long range aircraft detection.

3. Infrared Sensors for Tactical Uses. DARPA has initiated a new effort to exploit infrared sensor technology for tactical uses. The aim is to achieve new generations of infrared fire-and-forget missile seekers and target acquisition aids with quantum increases in performance at greatly reduced costs. A simulation and design activity has shown the capability of providing imaging infrared fire-and-forget seekers. In addition, factors of three to five cost reductions are projected. We are currently embarking on a fabrication program to demonstrate and test these concepts. If successful, this program will establish the technology base for advanced anti-tank missiles which will

operate day and night in degraded atmospheres and permit the gunner the safety of launch without the requirement to guide the missile to impact.

In our advanced tactical target acquisition effort, we are increasing the number of detectors of a thermal imager by making use of high density infrared focal planes. The result is an imager which can acquire targets at greater range than today's sensors and is capable of operating day and night in degraded atmospheres such as those encountered on the European continent. In addition, our current designs show 50% packaging and optics diameter reductions, easing integration into aircraft and vehicles and reducing costs.

In partnership with the Army's Night Vision Lab and Missile Command, we are fabricating a prototype of such a thermal imager for test by each of the three Services to assure a Tri-Service sensor. When completed, this program will provide proven technology for real time sensors which are capable of acquiring targets at ranges consistent with the requirements of advanced weapons systems.

4. X-Wing Aircraft. Analysis and wind tunnel experiments completed during the past year have shown that a unique air circulation control scheme, wherein air is blown over the edges of rotor blades, can furnish lift and can be controlled. This finding provides the basis for an X-Wing aircraft concept which would permit a flight vehicle that has the performance capabilities of a helicopter and a fixed wing aircraft. It

appears this can be achieved by use of a four-bladed rigid rotor that can be stopped at a forward velocity that allows the aircraft to sustain flight in a fixed wing mode. Based on these findings, a new initiative has been undertaken to design and test a blowing system and solve aero-elastic and blade/hub aerodynamic interference problems associated with the forward-swept blades in the fixed wing mode. Analysis shows this vehicle would have excellent vertical take-off performance with high payload-to-power ratios, good hover/low speed handling qualities, low down-wash velocities and temperatures, and low noise levels. In addition, it promises high speed (transonic) and long range in the fixed wing flight mode. Analysis shows that range and loiter time of an aircraft of this design may be greater than conventional helicopters. The program is a joint Navy-DARPA effort and is directed toward a flight demonstration of the concept.

5. Air-to-Air Missile. At the request of the DDR&E, DARPA has undertaken a new initiative to apply advanced technology in microprocessors, solid state transmitters, array antennas and aimable warheads to achieve an all-weather air-to-air missile with performance comparable to the AIM-7 Sparrow, but with less than one-third the weight of current AIM-7F. Key technical issues are low miss distance consistent with use of lightweight warheads, ECM resistance, high target detection ratios for a lock-on after launch missile, maneuvering target performance, and high reliability. We believe use of advanced digital

processing techniques can provide added ECM resistance, a launch-and-leave firing capability, and miss distance reduction. We are undertaking a system definition effort backed up by proof-of-concept demonstration of the key subsystem technologies. There is high potential payoff in being able to provide our F14 - F18 fighters with an all-weather mid-range missile of high effectiveness at greater than current ammunition loads. This system definition effort is being carried out in concert with the recently established Joint Air Force/Navy BVR (Beyond Visual Range) Project Office.

6. Netted Radars. Anti-radar developments of the past several years have shown that normal radar operations may become both ineffective and lethal on the battlefield of the future. Some of the developments which threaten radars are: (1) anti-radiation missiles, (2) fast, accurate emitter locators, and (3) air-deployed distributed jammers. One of the most effective responses to this threat is to internet battlefield radars (both fixed and mobile) and remotely operate them both as active devices (but intermittent), and as passive direction finding devices. In this way, the radar net can be used in a blinking or jittered PRF mode to confuse ARMs and emitter locators; it can "see" around jamming screens by use of unjammed inter-visible radars; it can operate passively as a multi-sensor direction finder; it can provide an integrated ground and air surveillance picture to higher command echelons as well as serving direct user needs; and it can be self-healing against direct attack. We have

initiated a new joint program with the Army to establish the needed radar modifications for improved performance and remote operations, net interconnections, processing terminals, and net architecture within the battlefield. The joint program will demonstrate operation of modified GFE radars in a mini-net; demonstrate unattended operation of a battlefield radar with false alarm rates low enough for network operation; produce a testbed radar tailored to the network needs; and define the architecture of an actual tactical net. The impact of this program, if successful, will be definition of a battlefield sensor net which maintains operation in a threat and ECM environment that would make normal radar operations extremely difficult.

7. Army Packet Radio Tactical Data Distribution Experiment. A new initiative is under development for a joint effort with the Army to evaluate the utility of the unique DARPA-developed packet radio technology in future Army tactical data distribution systems. The focus is on examining, in the context of an Army corps or division environment, this new radio-based, computer-communications system, which can potentially provide a number of essential capabilities to the battlefield of the 1985-1995 time frame including: wideband (100 to 400 Kbs), error-free data communications between tactical data computers and between terminals and these computers; voice communication; security; anti-jam, anti-spoof protection; efficient use of the

radio spectrum; support of mobile users; internetting with intercontinental and US networks; high degree of survivability and redundancy due to multiple routing strategies and multiple-repeater area coverage; and low-probability-of-intercept operation.

This program is jointly planned with the Army to insure that the relevant military issues are addressed and to provide necessary feedback to the technical packet radio system developers. Planning and initial ARPANET-based computer-communication training of a target Army unit is planned in FY 1977 with military packet radio-based experiments planned during the FY 1978-1981 time frame.

8. Gallium Arsenide Large Scale Integrated Circuits. Capitalizing on successful GaAs materials preparation and ion implantation processing research by DARPA in the FY 1975 - 1977 period, a new major effort will begin in FY 1978 to establish a LSI fabrication technology in GaAs. LSI circuits made using the unique properties of the compound semiconductor GaAs are potentially capable of a factor of 10 or greater increase in speed and decrease in power compared to silicon-based circuits. These increased capabilities are essential to meet future systems requirements in secure and/or LPI communications, ECM/ELINT, radar signal processing, and onboard data processing in surveillance from space.

9. Metal Matrix Composites. Metal matrix composites are substances made up of two or more materials to achieve a composite

having the best properties of each of its constituents. An example would be a dispersion of graphite fibers having strength at high temperatures in a ductile metal matrix. A new initiative is planned to explore metal matrix composites in two specific applications areas: (a) through the Navy (NRL), and with the cooperation of the Army (AMMRC), strengthening of long rod penetrators to decrease their buckling tendency on impact will be explored. Preliminary experiments have already shown that a metal matrix composite penetrator is much more efficient than the same penetrator without fiber reinforcement; and (b) through the Air Force and SAMSO we will explore use of metal matrix composites in space. Our motivation is twofold: (1) Present space satellites are vulnerable to fogging of their optics by residual volatile materials in the constituents from which they are constructed; and (2) metal matrix composites have a higher strength-to-weight ratio than presently-used metals and alloys. For example, the weight savings possible for an operational communication satellite through substitution of metal matrix composites would be 171 pounds (approximately 9% of the total satellite weight). Such weight savings could be used to (1) increase mean mission duration or effective life in orbit (by increasing channel redundancy) by approximately twofold at a cost savings of $60 million for a single launch, or (2) increase the number of active communication channels by 33%, thereby dramatically improving mission capability.

10. Forward Swept Wing. One of the important aspects associated with tactical air warfare aircraft is the ability to perform tight (high "g") turns without loss of speed. Directly related to this capability is the efficiency of the wing for developing the necessary high lift with a minimum increase in aircraft drag. Since the aircraft drag must be overcome by engine thrust, a more efficient wing will generally result in the need of a smaller engine, and, therefore, a lighter, less costly aircraft to perform a given mission. It is believed that by sweeping the vehicle wings forward rather than aft the potential exists for increases in the wing efficiency and a corresponding increase in the ability of the aircraft to perform the high "g" maneuvers. The reason for not using swept forward wings in the past is due to a structural problem known as aeroelastic divergence which has the effect of driving the wing weight up and negating the potential inherent advantages of the swept forward design. The advent of advanced composite structures with their unique material properties, changes this situation and there is now promise of eliminating the structural divergence problem. Moreover, the opportunity now exists for taking advantage of the forward swept efficiencies. DARPA has initiated a program with the objectives of determining the most efficient aerodynamic forward sweep aircraft designs and the methods for best utilizing advanced composite materials. The first phase of the program will consist of theoretical studies to be followed by extensive wind tunnel testing.

11. Use of Commercial Materiel in Tactical Troop Units. There is a recognized concern by the Military Services that rigorous government specifications to acquire commercial-type products may result in unnecessarily high costs. A new initiative is being undertaken in conjunction with the US Marine Corps to outfit a military unit with commercial, off-the-shelf clothing and equipment, and measure the impact on combat effectiveness and costs. While the cost effectiveness of specific items has previously been assessed, no effort has ever included supplying entire units. At the end of a two-year test of two units, one conventionally supplied, the other commercially supplied, the effectiveness of both units will be measured using DARPA-developed combat-effectiveness measures. Subsequently, the tradeoffs between cost and effectiveness will be assessed. It is envisioned that the two test units would be Marine Corps rifle companies, since the Marine Corps has shown strong interest in this project.